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THE SPECTRA OF MERCURY.

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INTRODUCTION.

THE spectrum of a substance in a vacuum tube assumes different forms as the conditions under which it is observed are made to vary. The discharge through many of the gases has been quite thoroughly studied, as it is affected by temperature and pressure in the tube and by the nature of the discharge.

The fact that mercury is used in most pumps and the great influence which even a very small percentage of its vapor has upon the spectrum of such a gas as hydrogen in a tube, points to the necessity for a detailed study of the mercury spectrum.[1]

Additional weight is added to the above reason by the work of Eder and Valenta, in which they announce their discovery of the band-spectrum and the possibility of breaking this up into a line-spectrum having a vastly greater number of lines than the one formerly known.

Further, since mercury is monatomic, its study should help answer the question as to whether a monatomic substance can

[1] "The effect of certain impurities on the spectra of some gases," E. P. Lewis, this JOURNAL, 10, 1899.

have a band spectrum which can be broken up into one showing lines only.[1]

It may be urged that in the spectrum from a tube, we get the effect of particles thrown off the glass walls and the electrodes, as well as that of the residual gases. Nevertheless, we know that a small amount of mercury vapor in a tube renders the effects due to the presence of some other gases in the tube small.[2] Accordingly, in studying the discharge through a tube of mercury vapor, we have conditions somewhat less complex than those usually presented when the spectra given by tubes are to be investigated.

APPARATUS.

The gratings used were a large concave one of 21 feet radius and a smaller one of 7 feet.

For obtaining the arc-spectrum, a direct current of about ten amperes was used. The spark and the discharge through tubes were obtained from an ordinary induction coil giving a spark 8 cm long; or from a coil the primary of which carried an alternating current from a Westinghouse dynamo making 130 complete oscillations per second. With no capacity in the secondary, the discharge from this latter coil was an alternating arc. With capacity, it gave a succession of strong sparks. The extreme length of spark obtainable in air was about 2 cm. Shortening the spark increased the rapidity of the succession, as was evident from the pitch of the note given out by the discharge.

For the vacuum tubes, German sodium glass was used. Though Jena glass stood heating better, it was more difficult to seal electrodes into, and at times it would develop longitudinal cracks several days after working and at some distance from a joint. For exhausting, the ordinary forms of mercury pump were used, with drying apparatus, etc. Pressures were read with a M'Leod gauge. Except for rough work, tubes were carefully cleaned and mercury was freshly distilled just before using. It was found that repeated sparking always raised the pressure of a tube joined to the pump. This was true, even when the sparking

[1] LOCKYER, *Proc. Roy. Soc.*, **21**, 1873. [2] LEWIS, *loc. cit.*

and exhausting were repeated at intervals for several days. Before sealing off from the pump, the mercury in the tube was boiled and the walls of the tube were heated.

ARC-SPECTRUM OF MERCURY.

Preliminary to a study of the spectra of mercury in tubes, it was deemed advisable to obtain the arc-spectrum. This was attempted by Liveing and Dewar, but they say they found it impossible to get more than comparatively few lines. Of the lines found, but one, $\lambda = 2536.8$, was reversed.

Kayser and Runge,[1] however, seem to have had no difficulty in obtaining many lines from the arc. They give a list of wave-lengths in their papers on the spectra of the elements.

The first attempts to obtain the arc-spectrum of mercury in this investigation met with small success. Carbon poles were used and the lower one was bored out to a depth of about two inches. This positive pole was filled with the sulphide and, in later attempts, with the metal itself. In neither case were more than a few lines obtained, and these were weak compared with those from the poles, even when a small current was used. Only the strong lines given by Kayser and Runge were found. It became clear that enough metal must be supplied so that it could boil off freely from the arc, for sometimes even when the pole was nearly filled, not a single mercury line appeared on the plate.

Finally, a long carbon was bored out and a rubber tube leading to a reservoir was attached to the lower end. This made it possible to keep the mercury at the very top of the pole. The results were satisfactory, a few minutes exposure giving on the plate all the lines found by Kayser and Runge in that region. In the extreme ultra-violet, an exposure of an hour with the large grating gave lines of wave-length as short as $\lambda = 1872$. In this ultra-violet region, the plates show some of the comparatively weak lines as coming from the entire space between the poles; others

[1] KAYSER and RUNGE, "Die Spectren der Elemente." 4 Abschnitt, 1891 *Abhandl. d. König. preuss. Akad. d. Wiss.*

are short on the plate, and seem to have come only from near the carbon terminals.

Some of the extreme ultra-violet lines given by Kayser and Runge were not found. Neither did $\lambda = 3305$, of intensity 6, appear on any plate, although a line at $\lambda = 3342$, to which they give an intensity of but 5, came out strongly.

The following additional arc-lines were noted and their wave-lengths found by measuring with a scale from standard mercury lines as given by Kayser and Runge.

Wave-length in Ångström units	Intensity	Character	Wave-length in Ångström units	Intensity	Character
2640.0	3	Double; very hazy	2194.2	1	
2352.5	2		2189.2	2	
2341.0	1		2186.6	1	
2323.0	1	Hazy	2172.1	1	
2284.2	2		2169.2	1	
2275.5	1		2001.6	1	
2259.2	1	Very hazy	1919.5	1	
2230.1	1		1876.0	2	
2227.9	1		1872.2	2	
2197.7	1				

It is difficult to estimate intensities of lines in this region, since the plates show a great deal of continuous spectrum.

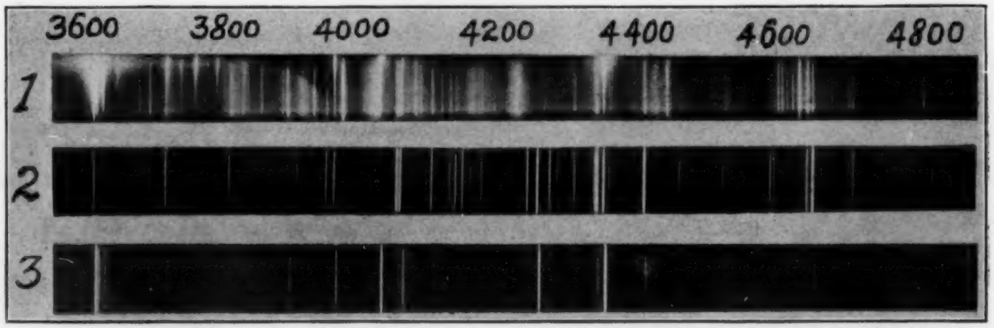
THE SPARK-SPECTRUM.

The study of the spark in air had for its object the investigation of the effects due to changing the conditions of the discharge, and also the determination of the principal air-lines which come out in the spectrum of the spark. A comparison, then, of spark plates with those showing the spectrum from tubes will give an idea of the effect due to the residuum of air in a tube.

EFFECT OF CAPACITY.

Using the large coil, a spark was obtained between an upper terminal of carbon and the mercury held in a broad dish. With no capacity in the secondary, this spark took the appearance of an alternating arc, and the spectrum obtained was that of the arc.

PLATE XII



1. Spectrum of Spark in Air between Platinum and Mercury
2. Spectrum from Tube Sealed off at Pressure of 0.003 mm: small Capacity in the Secondary
3. Same as 2, but Self-Induction in the Secondary

For example, the line $\lambda = 2967$ comes out very strongly in the arc and is given an intensity 10 by Kayser and Runge in their list. It also comes out strongly in the spark when capacity is used in the secondary. To a neighboring line, $\lambda = 2848$, Kayser and Runge give an intensity of 4 in the arc, but in the spark Eder and Valenta find it of intensity 10. With no capacity in the secondary of the discharge from the large coil, $\lambda = 2967$ still comes out strongly as compared with other arc-lines, while $\lambda = 2848$ decreases in intensity to about what it had in the arc.

As the capacity was increased, the hissing discharge became more disruptive in character and the characteristic spark-lines came out; the continuous spectrum also increased, and all the lines became less sharply defined, even when the light was taken from the upper part of the spark, quite away from the surface of the mercury.

The most clear-cut lines were got from the discharge of the small coil before the slit of the large grating, though the exposure was necessarily very long. Using the maximum capacity, the list of spark-lines was found substantially as given by Eder and Valenta.[1]

EFFECT OF SELF-INDUCTION.

The effect of the introduction of self-induction in the secondary was also studied.[2] The inductance coil used consisted of 200 m of copper wire wound in 9 layers of 30 turns each, each turn 6 mm from any other. The self-induction was 0.009 Henry.

Using this coil in the secondary, with capacity, the most noticeable effect on the discharge was the decrease in its violence, owing to the increased period of the oscillations. The general effect on the spectrum lines was to increase their sharpness, the continuous spectrum of the more violent discharge being cut out.

[1] EDER and VALENTA, "Die verschiedenen Spectren des Quecksilbers," Wien, 1894.

[2] HEMSALECH, "Sur les spectres des décharges oscillantes," *Comp. Rend.*, **129**, 5, 1899; *J. de Phys.*, Dec., 1899.

With self-induction in the secondary, the following lines which appear in both arc and spark spectra were reduced to their arc intensity.

Wave-length λ	Arc intensity	Spark intensity	Wave-length λ	Arc intensity	Spark intensity
2820	4	10	3562	4	6
2848	4	10	3790	2	8
3390	3	8	3984	4	8
3544	4	6			

Characteristic spark lines like

λ	Intensity
5426	8
5679	8

were cut out entirely. (See Plate XIV, 8.)

The lines

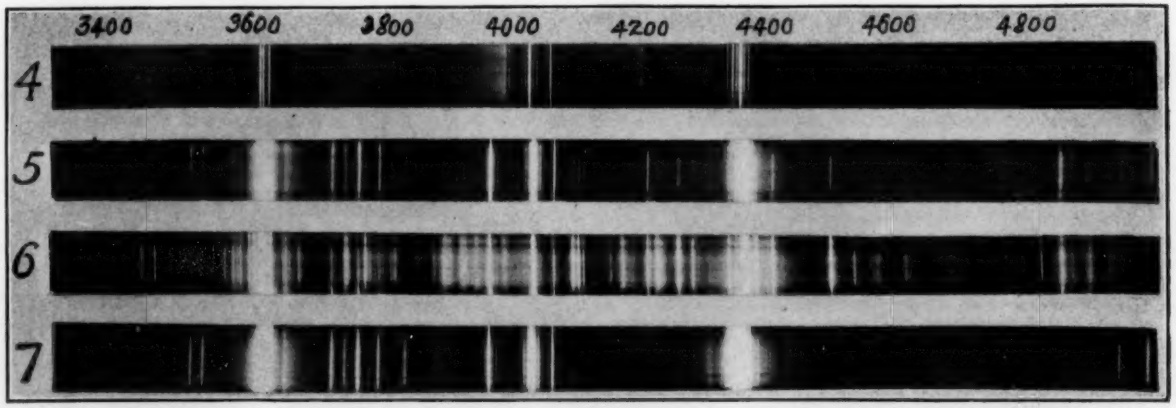
λ	Arc intensity	Spark intensity
5770	10	10
5790	10	10

compared with the line $\lambda = 5461$, whose intensity was 10 in both spark and arc, came out very much stronger for self-induction in the secondary. (Plate XIV, 8.) The effect of self-induction in the secondary is, then, to tend to reduce the spark to the arc and to sharpen the lines. As a result of this sharpening of the lines, $\lambda = 3663$ and $\lambda = 3131$ are found to be double in the spark in air. That the latter phenomenon was not a reversal was seen clearly by comparison with $\lambda = 2536$, where the reversal showed most clearly nearest the mercury terminal. With capacity but no self-induction, a very short exposure shows $\lambda = 3650$ reversed, and exceedingly broad and hazy. The introduction of self-induction brings out a single sharp line. (Plate XIV, 9.)

EFFECT OF LENGTH OF SPARK.

With a given capacity, that of a bank of six one-gallon Leyden jars, a thick spark about 2 cm long could be obtained, very disruptive and giving a note whose pitch was determined by the alternations in the primary of the coil. Shortening the spark raised the pitch of the discharge until, for a length of 3 mm, the

PLATE XIII



PHOTOGRAPHS OF SPECTRUM OF MERCURY IN A TUBE, TO SHOW EFFECTS OF VARYING CAPACITY, AND OF SELF-INDUCTION

4. Band Spectrum. No Capacity Used
5. Capacity One 1-qt. Jar
6. Capacity Two 1-gal. Jars
7. Capacity One 1-qt. Jar and Self-Induction in the Secondary

discharge was a sharp, hissing one, to the ear quite like that when no capacity was used, though in appearance it was still a spark. The spectrum of this short spark gave the arc-lines and some of those due to the spark. The arc-lines $\lambda = 5770$ and $\lambda = 5790$ came out equally well in both long and short sparks, while the characteristic spark lines $\lambda = 5426$ and $\lambda = 5679$ each of intensity 8, came out relatively much stronger in the long than in the short spark.

With self-induction in the secondary, the long and short sparks gave the same lines. It was thought that by comparing the lines obtained from a very long and from a very short spark, a shift might be observed.[1] The very great broadening of the lines in the former case made it impossible to make reliable micrometer settings. The self-induction in the secondary made the lines much less hazy, but also lessened the violence of the discharge.

SPECTRA OF MERCURY IN TUBES.

The best work on the spectra of mercury in tubes is that done by Eder and Valenta.[2] They discovered the band-spectrum given by mercury vapor distilling through a capillary. By using capacity in the secondary of the induction coil, these bands were broken up into an immense number of lines.

A more detailed study of the spectra from tubes containing mercury seemed desirable, including the effect of varying continuously the capacity and the self-induction; also the effect of changing the temperature of the tube and of different forms of discharge.

It seemed well, also, to make direct comparison of plates showing the spectrum of sparks in air with those obtained by the use of tubes whose conditions could be varied. While the coincidence of isolated lines cannot, be accepted as evidence of the effects due to the presence of air in the tube, a group of air-lines appearing on a plate from a tube might be identified with certainty. Some idea would then be obtained of the effect

[1] WILSING, this JOURNAL, **10**, 1899.

[2] EDER and VALENTA, "Die verschiedenen Spectren des Quecksilbers," Wien, 1894.

of air as the conditions of the tube were changed. The use of external electrodes would also simplify the conditions.

The first question naturally had to do with the form of tube to be used. The first one tried was similar to that used by Eder and Valenta, and consisted of an ordinary "end-on" tube with about 6 cm of capillary, the light passing through a quartz plate sealed on with liquid glass. But hardened sodium silicate will stand only a moderate temperature and since the work was to be mainly qualitative, it was determined to use "side-on" tubes, although by this the study of the spectra was confined to wave-lengths which glass allowed to pass. A great increase of light came from using a "side-on" tube and since the capillary could be drawn with very thin walls, the shorter wave-lengths were still allowed to pass.

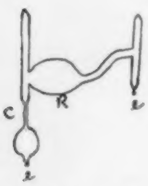


FIG. 1.

FIG. 2.

The essential feature of the tube must be the possibility of keeping it in a steady state for several hours, if need be. Many forms were made and tried. The spectra obtained could be observed to go through series of changes and could at will be made to repeat these changes. The difficulty was to keep each form constant until it could be photographed. The tubes selected were as shown in Figs. 1 and 2.

The electrodes of platinum are at *e*.

R is a reservoir for mercury.

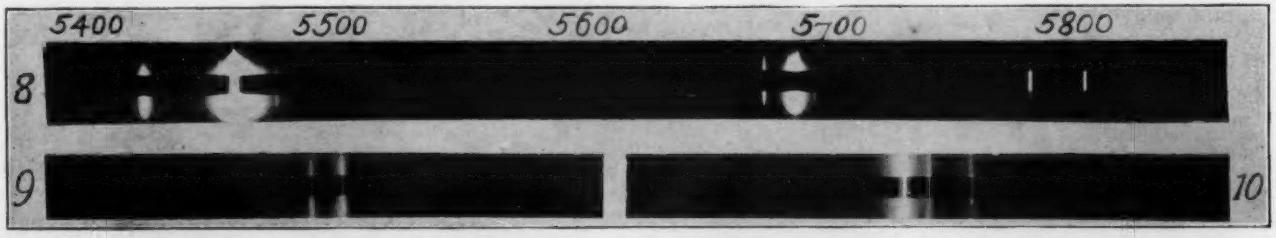
C is the capillary.

By heating the reservoir, the mercury would distil through the capillary. The platinum at the electrodes was covered with mercury.

Upon taking up the study of the tube spectra, it seemed possible that the bands might be due to the glass or to an oxide of mercury formed in the tube.

To free the tubes as far as possible from air, they were kept on the pump for several days and sparked repeatedly. In addition, the mercury was boiled and the whole tube was heated before sealing off.

PLATE XIV



PHOTOGRAPHS SHOWING EFFECT OF SELF-INDUCTION ON SPARK IN AIR

OUTSIDE, CAPACITY BUT NO SELF-INDUCTION

8. INSIDE, CAPACITY AND SELF-INDUCTION

9. SAME AS 8 FOR $\lambda = 3125$

10. SAME AS 8 FOR $\lambda = 3650$

Such a tube containing no glass of internal diameter less than 8 mm was found to show bands where the discharge left the surface of the mercury, both at anode and cathode; and also in the tube at any point between the electrodes. This seemed to make the use of a capillary unobjectionable. Accordingly, a tube of type 1 had its lower electrode filled until the mercury stood in the capillary. The bands were shown strongest from the surface of the liquid, but appeared throughout the tube. This was without other heat than that produced by the discharge from the small coil. At the electrodes, the temperature was perhaps 70° C. The pressure in this second tube had been read 0.1 mm at sealing off. This band-spectrum was identified with that of Eder and Valenta.

Using this same tube, an attempt was made to obtain the line-spectrum of Eder and Valenta by putting capacity in the secondary. To the eye, the only change was that the discharge was not so bright.

Plates including a region between $\lambda = 3000$ and $\lambda = 5400$ showed one band at $\lambda = 4012$ broken up and a few lines to replace it. Capacities were used varying from zero to that of six one-gallon jars, giving no new effect.

The discharge through the tube was made stronger. The tube became hot and a few of the characteristic arc-lines came out strongly, the bands disappearing. Capacity brought out a few new lines. Using a weaker discharge, a small flame under the upper reservoir caused the mercury to distil through the capillary. The introduction of capacity had little effect except after mercury had condensed in the large tube just above the capillary. Until this flowed down, the capillary discharge became a creamy tint instead of green, and showed a spectrum of many lines, for a moment only. It was found that a tube like 2 gave bands, and by heating the reservoir, the light from the distilling mercury of the capillary could be made to give the line-spectrum for any desired length of time.

A tube with a capillary of ¼ mm internal diameter and sealed off at a pressure of 0.01 mm of mercury was slightly

heated, and gave bands which broke up into lines when capacity was used. Too much heat prevented the discharge for a given capacity, as did also too much capacity for a given heating.

With much stronger heating, the discharge would again pass, with a brilliant green color. Capacity made the discharge dazzlingly bright, its spectrum showing continuous spectrum and in addition many lines, some of them considerably broadened. For still stronger heating, the crowd of lines sank back and were merged into the continuous spectrum, only a few of the strongest arc-lines standing out slightly.

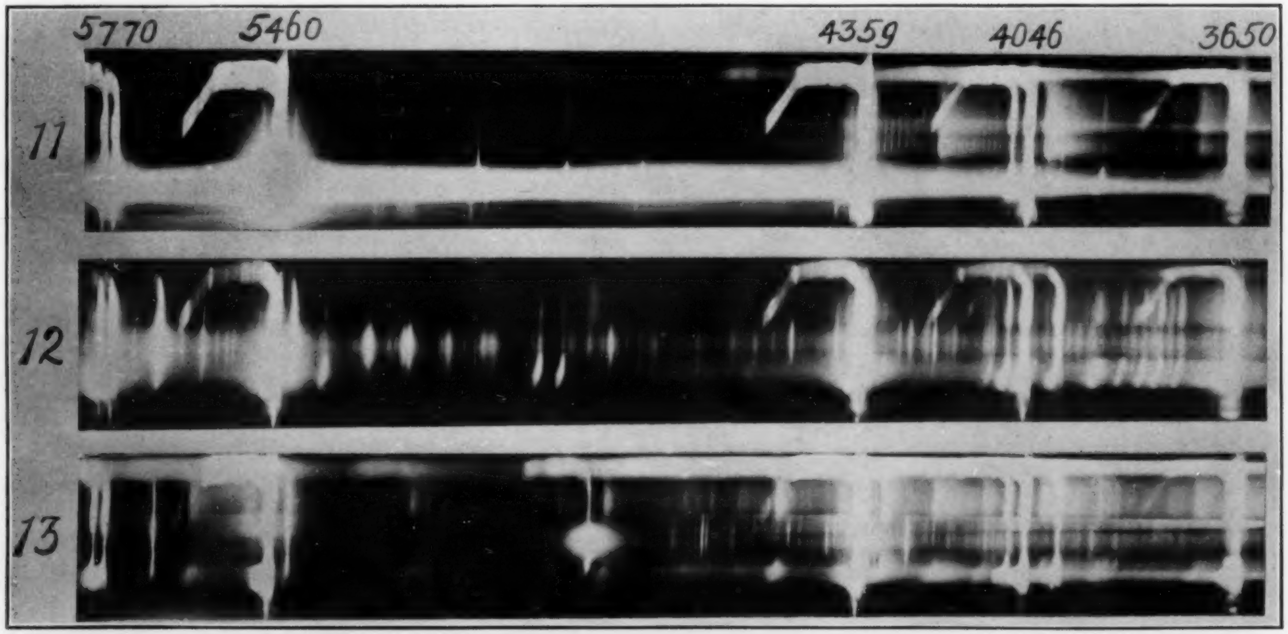
EFFECT OF CAPACITY.

A tube of type 2 sealed off at a pressure of 0.01 mm of mercury was heated with a very small gas-flame held about 10 cm below the reservoir. After several hours of such heating, the spectrum showed lines or bands according as capacity was or was not used in the secondary of the small coil. The conditions were then assumed constant and a series of plates was taken for a capacity varying from zero to the largest that would allow the discharge to pass, viz., that of two one-gallon jars. With a very small capacity, the spectrum was the same as with none, showing the bands. With a one-pint jar in the secondary, the most noticeable change was the appearance of $\lambda = 3984$ and the broadening toward the violet of the group at $\lambda = 3950$. A few new hazy lines appeared in other parts of the spectrum. The line $\lambda = 4216$ came out and the band near it weakened. Using a one-gallon jar and keeping the other conditions constant and the same as for the preceding cases, the bands disappeared entirely, many new lines coming out. With two large jars the effect was but slightly different from that obtained with but one. (See Plate XIII, 4, 5, 6.)

In general, these results show that a gradual increase of capacity in the secondary changes the spectrum from a band to a line-spectrum. The intermediate conditions may be obtained and photographed.

With a too great capacity, of course no discharge passes, but with the maximum which may be used for a given temperature

PLATE XV



SPECTRUM FROM ENTIRE TUBE OF TYPE 2

11. While Strongly Heated and with No Capacity in the Secondary
12. Same, but with Capacity
13. Same as 12, but Less Strongly Heated

and current, there is brought out the maximum number of lines in the series of changes from bands to lines and these lines are of greatest sharpness for the given temperature.

With as wide a range of current difference as could be used through the primary of the small coil, the spectra were essentially the same, the discharge differing only in brightness.

EFFECT OF SELF-INDUCTION.

When the inductance-coil was put in the secondary, with capacity, the discharge through the tube decreased in brightness. The change in the spectrum was analogous to that produced in the case of the spark in air. The principal arc-lines, such as

$$\begin{aligned} \lambda = {} & 3650 \\ & 3984 \\ & 4047 \\ & 4078 \\ & 4360 \end{aligned}$$

were brought out strongly, with considerable continuous spectrum, though in general the lines were sharper than when no coil was used in the secondary. A vast number of lines were cut out entirely, or very much weakened. (See Plate XIII, 7.) For a smaller self-induction, fewer lines were cut out.

By the use of such a coil in the secondary, it seems possible, therefore, to reduce the spectrum obtained by breaking up the bands to one showing only the strongest lines of the arc and of the spark in air.

For the above series of plates, showing the effects of self-induction and of varying capacity, the same tube was used throughout. The conditions were kept as nearly constant as possible, and the observations were extended over a period of fourteen hours. The tube was then allowed to cool, and the spectrum obtained was the same as that before the heating.

PRESSURE.

At comparatively high pressures the principal arc-lines of mercury are given by the spectra of tubes. The bands appear while the tube contains enough nitrogen to obscure everything

else in the ultra-violet. As the pressure is decreased, the amount of heat, in addition to that from the current needed to give the brilliant discharge, grows less, and it is consequently easier to get the most abundant line-spectrum. A small capacity gives these lines, and they persist throughout the capillary. The character of the lines also changes, for while with more heat the lines are hazy and shaded on both sides, though more toward the violet, the lines from tubes heated only by a small current are sharp and clear. (See Plate XII, 2.)

Indeed, this sharp line spectrum would scarcely be recognized as related to that obtained at higher pressures. That it is so related was shown by exposing that part of the tube near where the capillary met the larger tube. From the same exposure the one part of the plate showed bands, the other this sharp line-spectrum.

On slightly heating this tube, the discharge changed from its bluish tint in the capillary to the characteristic brilliant one, and with capacity, this yielded the same spectrum obtained from tubes sealed off at higher pressure and examined when at higher temperature; also the same lines, so far as eye observation could determine, were seen in tubes sealed off at yet higher pressure and studied when still more strongly heated, but not photographed, owing to the difficulty of keeping their condition constant for any length of time.

The pressures at which the above three sets of tubes were sealed off from the pump were given by the gauge at 1 mm, 0.06 mm, and 0.004 mm.

AIR LINES.

Since the presence of even a trace of mercury vapor in a tube is sufficient to show the lines

$$\begin{aligned}\lambda &= 5769\\ &\ 5461\\ &\ 4358\end{aligned}$$

and seems also to reduce the intensity of the lines due to a gas like hydrogen, a comparison was made between plates obtained from a tube and those of the spark in air.

A tube was strongly heated, and sparked while on the pump, and was sealed off at a pressure of about 0.003 mm. This tube gave a spectrum of sharp lines. Plates taken with the small grating, using a spark between platinum and mercury, showed short lines due to the electrodes, but air-lines extending entirely across the plate. A comparison of spark-plates with those from tubes showed the following groups of air-lines on both (see Plate XII, 1, 2):

λ=4070
4120
4182
4318
4350
4415
4705

Other lines showed coincidences, but only in cases like the above, where an entire group was the same, could it be said that the air-lines persisted in the tube. The above groups were sometimes of scattered lines; in several cases they were of fine, sharp lines, close together and equidistant. In every case the character of the group was such as to make certain its identification on the two sets of plates.

The introduction of an inductance-coil in the secondary either very much weakened or entirely cut out every group noted above. (Plate XII, 3.) When this tube was heated and capacity was used in the secondary, the spectrum given was quite distinct from the one previously obtained with capacity but no heating. If the air affected this second spectrum, it was in a way not easily traced. From tubes sealed off at higher pressure, and which were not heated except by the discharge, the band-spectrum of mercury was obtained, with only traces of the groups of air-lines. The air lines seem, therefore, to come out most strongly at very low pressures and temperatures, but to disappear under conditions giving the bands or the "spectrum of many lines." These air-lines reappear in the spectrum from a tube that has been heated until they disappear, but which is examined when again cool.

The color of the capillary of a tube at a pressure of 1 mm, and not heated, was purple. For a lower pressure, the effect of the nitrogen was lost, and the capillary became pink when the discharge first passed, but soon changed to green. When a tube contained capillaries of different sizes, the pink persisted longest in the finest tubes. For a pressure of a few thousandths of a millimeter, the capillary became blue. But when strongly heated, all tubes showed the characteristic green of the mercury $\lambda = 5461$, and with capacity gave the dazzlingly bright discharge.

STUDY OF THE ENTIRE TUBE.

Using a plane grating as objective, a complete set of plates was taken from the tube used in studying the changes due to varying the capacity. The advantage of thus photographing the entire tube is obvious, since such a plate gives an image of every part of the tube for each wave-length coming from that part. A small grating held in the hand was found much better than the ordinary direct-vision spectroscope for watching the discharge through a tube so that it might be kept constant during an exposure.

To photograph the entire tube, it was set up at a distance of 4 m from a 5½-inch plane grating. The light from the grating was brought to a focus on a plate about 2 m distant by means of a quartz lens. The region thus obtained was from $\lambda = 3200$ to $\lambda = 5800$.

When heated until the brilliant discharge passed, the bands were shown from the capillary and from the large part of the tube between capillary and anode, but not between capillary and cathode, where only a few lines appeared, broad and hazy in the continuous spectrum. With capacity, the line-spectrum appeared, with no trace of bands. In general, the lines persist throughout the tube. One line in the blue comes out in the capillary and on the side toward the anode; two others in the blue come out in the capillary and on the side toward the cathode, as does also one in the green. But few lines continue down to the boiling mercury in the reservoir, those doing so being principally the strong arc-lines.

If the heat is decreased and no capacity used, the discharge becomes less brilliant and bands at about $\lambda = 5570$ and $\lambda = 4850$ appear, which did not come out when more heat was used. On putting capacity into the secondary, the band-spectrum in the capillary gave way to one showing many lines, though in the large tube toward the anode the bands persisted, as they also did, faintly, toward the cathode. (Plate XV.)

The effect of the introduction of self-induction with capacity was to reduce, or to cut out entirely, throughout the tube, many lines brought out by capacity, noticeably in the blue and blue-green.

Tubes with external electrodes were also used. The form was that of Fig. 3. The electrodes were of tin-foil, wrapped tightly around the glass and then wound with wire. The discharge was not nearly so bright as that obtained from tubes whose platinum terminals made direct contact with the mercury in the bulbs. The spectra from tubes of different sizes and of different kinds of glass showed bands. One of these tubes was so small that the path of the discharge in the tube was not more than 4 cm. Before sealing off from the pump, it was very strongly heated. In plates showing bands from these tubes were some lines which are probably due to glass, since they do not come out with tubes of the first kind. Attempts to break up the bands from tubes of type 3 were not successful. Plates from these tubes obtained with the plane grating as objective showed the bands on both sides of a globule of mercury in the capillary. Some lines appear on one side of the capillary and but faintly, or not at all, on the other.

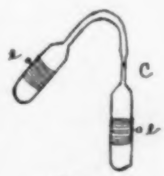


FIG. 3.

ALTERNATING DISCHARGE.

To determine the effect of using the alternating discharge from the large coil, tubes capable of use with large currents were made. With such a discharge, the small capillary was melted at once and one of heavy wall and 1 mm bore showed much continuous spectrum. With a tube of 2 mm inside diameter

the large coil with the bank of six jars in the secondary gave, with $\frac{1}{60}$ the time of exposure, a spectrum essentially the same as that obtained by using the smaller coil. The air-coil with the above discharge gave results similar to those already described. The intense heat developed by the heavy alternating current made it impossible to obtain the bands.

That the resistance of a tube of type 2 to the passage of such a discharge is not only at the electrodes, but also depends on the length of path to be followed, was shown conclusively. The mercury distilling from the electrodes into the reservoir, the length of the path was increased until the discharge would no longer pass. Refilling the arms of the tube from the reservoir, the discharge again passed. The tube was of the same internal diameter throughout.

RESULTS.

The arc-spectrum was obtained substantially as given by Kayser and Runge. A few additional lines in the extreme ultraviolet were noted.

By increase of capacity in the secondary of a coil giving an alternating discharge, the spectrum changed from that of the arc to one containing the characteristic spark-lines. The introduction of self-induction in the secondary of such a coil tends to reduce the spectrum of the spark to that of the arc. A long spark showed lines which were not given by a very short one.

Using a tube, bands were obtained with light directly off the surface of the mercury, both at anode and cathode of a large tube. On heating the tube, the bands disappeared, those in the shortest wave-lengths remaining longest. Capacity breaks up these bands, throughout the tube if it is heated sufficiently; otherwise, only in the capillary and near the cathode where the discharge produces the greatest heating. Self-induction accentuates the arc-lines at the expense of other lines due to very special conditions. By varying the capacity, it was possible to pass continuously from the band to the line spectrum.

For very low pressures, groups of air-lines come out; but are not identified in tubes at higher pressure or in tubes sealed off at low pressure and studied when heated.

The discharge from an ordinary induction coil gave the same spectrum as that from a very strong alternating current.

This investigation was begun at the suggestion of Professor Ames and was carried out under the supervision of the Directors of the Laboratory, Professor Rowland and Professor Ames, whom the writer takes this opportunity of thanking for their assistance, at all times most generously given. Mr. Lewis E. Jewell rendered most valuable assistance throughout the course of the work.

PHYSICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY,
June 1900.

AN INVESTIGATION OF THE ZEEMAN EFFECT,

WITH REFERENCE TO CADMIUM, ZINC, MAGNESIUM, IRON, NICKEL, TITANIUM, CARBON, CALCIUM, ALUMINIUM, SILICON, AND MERCURY.

By HERBERT M. REESE.

THEORY.

WITH few exceptions, all theories advanced so far to account for the Zeeman effect rest on the fundamental ideas of Lorentz[1] or of Larmor,[2] which agree in ascribing to the small particles of matter electric charges which are inseparable from them. Some theories, such as that of Voigt,[3] do not expressly mention charged particles, but introduce into the equations arbitrary terms which are similar to those characteristic of the motion of a charged body.

The simple theory which Lorentz[4] first advanced to account for Zeeman's discovery of the widening of the lines, and which enabled him to predict the doublet and triplet on further resolution, regarded as the source of light a single positively or negatively charged particle, acted upon only by an elastic force toward a position of equilibrium and another force normal to its motion and the magnetic induction, and equal numerically to the continued product of the charge, the velocity, and the resolved part of the magnetic force at right angles to the velocity. Even before the discovery of quadruplets and other complexities, Lorentz[5] began an investigation to determine whether variations from the triplet form were not to be expected. Starting with the idea of a perfectly general molecule, having n degrees of

[1] *Archives Neerlandaises*, Vol. XXV.

[2] *Phil. Trans.*, A, 1895, p. 718; A, 1894, p. 812.

[3] *Wied. Annalen*, No. 2, 1899, p. 345; No. 6, 1899, p. 352; No. 9, 1899, p. 290; No. 2, 1900, pp. 376 and 389.

[4] ZEEMAN, *Phil. Mag.*, March 1897, p. 226.

[5] *Wied. Annalen*, **63**, 278, and this JOURNAL, **9**, 37.

freedom, he showed that if p of these are equivalent without the magnetic field, the presence of the field will cause the single spectral line corresponding to them to break up into a p-fold group. Lorentz does not regard this explanation of complicated effects as satisfactory, however, owing to the difficulty of conceiving a system having more than three equivalent modes of vibration.

Preston[1] has brought forward, to account for complicated lines, a paper written by Stoney[2] in explanation of those groups of lines in the natural spectra of the elements which make up the so-called series. The suggestions that he makes are purely kinematical. He shows that if we have superimposed upon a motion in an elliptical orbit certain auxiliary motions such as a revolution of the plane of the orbit about a line inclined to it, or a revolution of the apse-lines in the plane of the orbit, the original single period will be replaced by two or more, differing slightly from it. Preston makes no suggestion as to how such auxiliary motions might be brought about physically except in one case. If we regard the vibrating ion as equivalent to a little magnet, the external magnetic force would tend to place the orbital plane perpendicular to the lines of force, and before coming to rest in this position the normal to the plane would make pendulum-like oscillations which would cause a doubling of the central line of the triplet, giving the well-known quadruplet. A single moving ion, however, differs in some essential points from a closed conducting circuit or its equivalent magnet, and it would seem that if any such directive force exists it is fully taken account of in the equations of motion, as given by Lorentz in Zeeman's paper, provided the assumption there made as to the forces acting on the ion are valid. The introduction of the elastic force toward a position of equilibrium seems reasonable, as a central force varying as any power of the distance other than the first would make the period dependent upon the amplitude, which can hardly be the case in light-vibrations; for apparently the position of a line in the spectrum is exactly the

[1] *Phil. Mag.*, **47**, 165. [2] *Sci. Trans. Roy. Dub. Soc.*, **4**, 563.

same whether it be very intense or quite feeble. Partial justification for making the magnetic effect on the ion equal to that which would act on an element of a conductor carrying a current equal to the product of the charge and velocity of the ion, is found in Professor Rowland's experiment carried out in Berlin in 1876, and repeated by Röntgen, Huchinson, and others, in which a magnet is deflected by rapidly rotating a charged disk. In this case, however, the rotating disk formed a closed circuit, without the interposition of displacement currents in the ether, and such is not the case with an isolated charge moving as a whole. Even if we admit, however, in the absence of any reason to believe otherwise, that a moving charge is equivalent to an element of current, we cannot look upon the moving ion as equivalent to a complete conducting circuit coinciding with the orbit, as Preston evidently does, for a conducting circuit is the seat of electromagnetic effects throughout its whole length at once, which are constant so long as the current-strength does not change; whereas the electric and magnetic quantities due to a moving charge are functions of the instantaneous position and velocity of the ion, and are not directly affected by the position and velocity at any other point of the orbit.

Voigt[1] has published a theory in which he shows that by introducing into the equations of motion terms of a suitable form he can account for many of the complicated effects that have been observed. The theory is unsatisfactory in that no physical reason is offered why such terms should be brought in. An interesting point is the prediction that in the case of the triplet in a weak field the red component should be more intense than the violet, and not so far from the central line, a prediction that has been verified by Zeeman[2] for a number of lines.

EXPERIMENTAL METHODS.

In every case the source of light in these experiments was an electric spark between terminals (generally metallic) in air. A few attempts were made to work with the oxyhydrogen flame

[1] *Loc. cit.* [2] *Roy. Acad. of Sci., Amsterdam*, Dec. 30, 1899.

and with a vacuum tube, but in neither case could sufficient light be thrown on the grating to make the lines bright enough to see or photograph. The spark was placed between the poles of a strong electro-magnet and the light from it focused on the slit of a concave grating spectroscope, the mounting of which was of the usual type with the slit at the vertex of the right angle, the grating and camera-box being at opposite ends of the movable hypotenuse. The spectra were photographed upon plates 11 inches long and 1¼ inches wide (with a few exceptions), which, after being developed, fixed, and dried, were measured on a dividing-engine designed by Professor Rowland and made under his direction, especially for the construction of his table of the solar spectrum. Separate records were kept in different notebooks of the circumstances under which each plate was taken and of the measurements taken on the dividing-engine.

The plan of the general arrangement of apparatus is as follows: An alternating current of 133 cycles per second, and 100 volts electromotive force was received from the dynamo room and passed through the primaries of three step-up transformers. The secondaries were connected in series, giving a total E. M. F. of 750 volts in the secondary circuit. The secondary current was passed through the primary coil of a large induction coil, the secondary terminals of which were connected to the spark terminals placed between the poles of the magnet. They were also connected with the inner and outer coatings of a battery of Leyden jars, each of about one gallon capacity. In most cases six of these jars were used, but sometimes a less number. In a few instances a small self-induction was introduced in the circuit including the Leyden jars and the spark, in order to make diffuse lines sharper. Without the self-induction the spark was thick and bright and made a loud tearing sound. The presence of self-induction caused a slight flame-like appearance on the side of the spark, similar to that seen in the carbon arc, and deadened the sound to a considerable degree. As a rule the spark was only one or two millimeters long, because if the gap were made wider the current would take the shorter path through

the pole-tip of the magnet. Attempts were made to prevent this by putting layers of insulating material between the pole-tips and the terminals; but in every case the current would pierce them; so that it was found far better to use nothing of the kind.

The terminals were sometimes rods of the metal to be investigated, about ⅛ inch in diameter and 4 inches long; sometimes larger pieces soldered or screwed to brass rods of this size. Often one terminal was of the metal to be investigated and the other of brass, or of another metal having lines in the same region. In the latter case the spectra of two substances appeared on the same plate, which was never a disadvantage, and sometimes was a help. For getting the spectrum of nickel a five-cent piece was found most convenient, as the alloy used in these coins is non-magnetic. Some trouble was experienced in using iron terminals, owing to the force with which they were attracted to the magnet, but they were finally held rigidly in place by fastening them between screws on pieces of board just long enough to reach between the flanges of the magnet. Later some plates were taken of the spectrum of the spark between small carbon terminals, and it was found that the spectrum of iron, as well as those of some other impurities, came out very strongly. Indeed, some such method as this must be used if measurements of the field-strength are made, for the introduction of iron terminals greatly alters the distribution of the lines of force. For taking the spectrum of mercury a small brass rod was bored out and mercury led up through it from a reservoir, the spark passing between the surface of the mercury and another brass terminal set opposite it. In all cases the terminals were filed or ground as flat as possible to avoid sparking to the pole-tips.

Two different magnets have been used. During the spring of 1898, and all the following scholastic year, a small but powerful magnet of the Ruhmkorff form was used, giving a maximum working field of about 28500 C. G. S. units. It had several sets of pole-tips, but for observations across the lines of force we always used a pair with spherical faces of about ¾ inch radius.

For observations along the field pole-tips with flat faces were used, one of which was bored out to allow the light to pass through. This magnet was so placed that the spark came directly in line with grating and slit, and was arranged so that it could be readily turned through ninety degrees. It was excited by a current of 35 amperes or less, according to requirements.

During the past autumn a much larger magnet was constructed, with the intention of obtaining a field which should be more uniform and more convenient for manipulation than that given by the Ruhmkorff magnet. The pole-tips are perfectly flat and are 1½ inches in diameter; throughout the whole space, except very near the edges, the field is quite uniform when the space between is about 3.4 millimeters wide.

Owing to the size of this magnet it was impossible to place it directly in line with slit and grating, so that it was set out from the wall and the light was totally reflected at right angles by a glass prism, which was replaced by a quartz one for ultraviolet radiations.

The strength of the field was measured by an exploring coil connected with a d'Arsonval ballistic galvanometer in a distant room.

When it was desired to analyze the light for polarization it was made to pass through a large Nicol's prism before passing through glass or quartz.

The light was focused on the slit by means of a converging quartz lens. In the first arrangement the lens used was 1½ inches in diameter, 12 inches in focal length, while that used with the large magnet was 2½ inches in diameter, 21 inches focal length.

The concave grating was ruled with 15,000 lines per inch over a space of 5¾ inches, and its radius was 13 feet 3 inches. It gave very good definition, but none of the spectra were at all bright except the first, which was not used on account of the small dispersion. The third spectrum was used up to wavelength 4600, but beyond that the second had to be used, because owing to an alteration which had previously been made on one

of the carriages, the beam could not be pushed beyond this point.

For wave-lengths below 5000 Seed's "Gilt Edge" plates were used, above this point Cramer's "Isochromatic fast" plates. The length of exposure varied from fifteen minutes to an hour and a half. The negatives were developed and fixed in the usual manner.

A full description of the dividing-engine and its accessories is given by W. J. Humphreys in the ASTROPHYSICAL JOURNAL for October 1897, page 169, so that nothing further need be said of them here.

RESULTS.

The object of this investigation was to study, in a general way, the spectra of various elements in the magnetic field, to determine the law of variation with the strength of the field, and to verify as far as possible the results obtained by others in regard to complicated lines.

For determining the law of variation of $\Delta\lambda$, the separation between the extreme lateral components of the magnetic group, and the strength of the field, a number of plates were taken of the same lines with fields varying from 6125 to 26580 C. G. S. units. One such series was taken with the lines 4678.37, 4800.09, 5086.06 of cadmium, and 4680.38, 4722.26, 4810.71 of zinc, on the same plates, one of the spark-terminals being of cadmium and the other of zinc. A similar series was taken with cadmium and magnesium terminals, giving simultaneously the lines 5086.06 of cadmium and 5167.55, 5172.87, and 5183.84 of magnesium. These lines were selected as offering wide separation together with a considerable variety of complexity. They are the lines for which Preston determined the law that homologous lines in the spectra of similar elements show similar magnetic effects. The lines 4678.37, 4680.38, and 5167.55, are sharp triplets, 4800.09, 4722.26, and 5172.87 are sextuplets, and 5086.06, 4810.71, and 5183.84 are diffuse triplets. After measuring the plates a curve was plotted for each line with field strengths as abscissae and separations as ordinates. The sextuplets appear

PLATE XVI

EFFECT OF A FIELD OF 27000 C. G. S. UNITS ON THE CADMIUM LINES $\lambda\lambda 4678$, 4800, AND THE ZINC LINES $\lambda\lambda 4680$, 4722, 4810

as such only in the strongest fields, therefore in measuring them they were treated as quadruplets, the measurement given as $\Delta\lambda$ being the distance between the mean of the two lateral com-

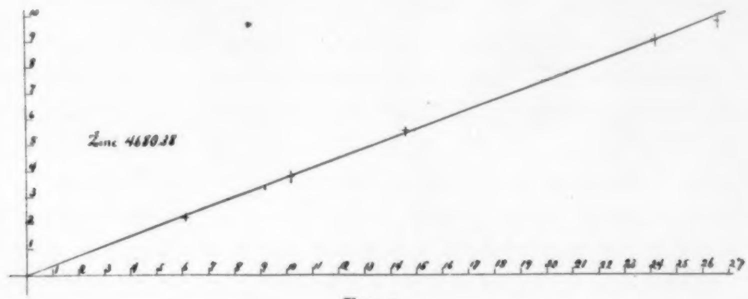


FIG. 1.

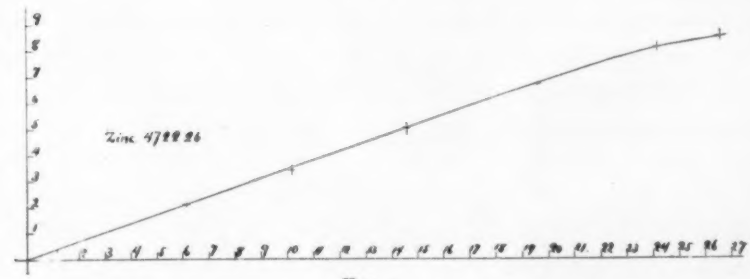


FIG. 2.

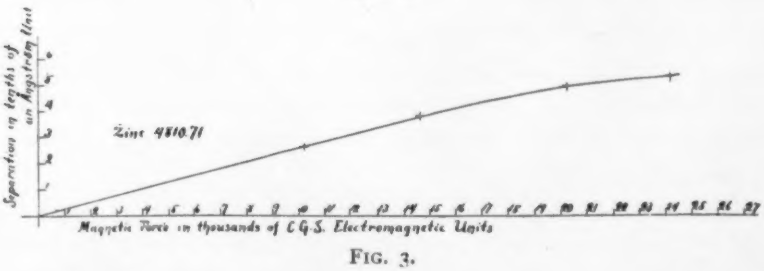


FIG. 3.

ponents on one side and that of those on the other. The appearance of these lines is illustrated in Plate XVII.

The pair of lines at *b* are polarized normal to the lines of force, those at *a* and *c* along the lines of force.

The curves obtained for the three zinc lines are shown in Figs. 1, 2, and 3. The curve for the triplet is perfectly straight

within experimental errors, except that it shows a slight tendency to droop at the highest field attainable, as if the separation approached a limiting value. This tendency is very slight, however, and may merely be due to an error in measurement. The curve for the quadruplet, however, shows this tendency to a greater degree, and in that for the diffuse triplet it is quite pronounced, beginning at a field-strength of 20200 units, the lower portion being still very straight. It must be admitted that in this case the measurements of $\Delta\lambda$ are not so reliable as those given in Figs. 1 and 2, owing to the character of the line, but I do not think errors of measurement can account for such a great deviation from a straight line. The curves for the cadmium lines 4678.37, 4800.09, and 5086.06 are almost identical respectively with Figs. 1, 2, and 3, except that the curve for 5086.06 is not complete, this being a rather hard line to photograph. The three magnesium lines also gave curves of the same character, although here the curve for the sharp triplet 5167.55 shows no tendency to droop, while this tendency in the case of the other two lines is less marked than with the corresponding lines of zinc and cadmium. I do not regard the results with the magnesium lines as being quite so trustworthy as those with zinc and cadmium, as the magnesium lines, especially 5167.55, were hard to photograph, and on most of my plates all three are rather faint, making accurate measurement of the separation difficult. Moreover, measurements on the zinc and cadmium plates are each the mean of eight observations, while only four were taken on the magnesium plates.

In taking these plates a Nicol's prism was used to block out light polarized in a plane normal to the lines of force, except in the stronger fields, where the separation was strong, for all these lines are shaded on one side, especially in the weaker fields, and the "diffuse triplets" were never clearly separated. It seems to be a general law, so far as my observations go, that in the case of heavily shaded lines the effect of the field, apart from the true separation of the Zeeman effect itself, is to destroy the shading and make the line sharper. Besides the above-mentioned

lines, this is shown in the magnesium lines 3838.44, 3832.46, and 3829.5.

Another means of making the lines sharper is self-induction in the spark circuit. This also has the effect of making them fainter, an effect which seems to be more marked for some substances than for others. Some plates were taken in this way, using cadmium and zinc terminals, of the lines 4678, 4722, 4800, and 4810, and it was found that the zinc lines were rendered scarcely visible by an amount of self-induction which left the cadmium lines still of a fair intensity.

My plates in this region confirm Preston's results with reference to corresponding lines in the spectra of cadmium, magnesium, and zinc. As already remarked, three of the lines are sharp triplets, three are sextuplets, and the other three are diffuse triplets, which on my plates show no indications of a more composite character. For each of these lines the value of $\frac{\Delta\lambda}{H\lambda^2}$ was calculated, using the lower straight portion of the curve for this purpose, and the values are given below, λ and $\Delta\lambda$ being measured in centimeters, and H in C. G. S. electromagnetic units.

Substance	Line	$\frac{\Delta\lambda}{H\lambda^2}$
Cadmium	4678.37	17×10^{-5}
Cadmium	4800.09	15.5×10^{-5}
Cadmium	5086.06	10.5×10^{-5}
Zinc	4680.38	17×10^{-5}
Zinc	4722.26	15.3×10^{-5}
Zinc	4810.71	11.3×10^{-5}
Magnesium	5167.55	16.7×10^{-5}
Magnesium	5172.87	14.9×10^{-5}
Magnesium	5183.84	10.5×10^{-5}

Preston gives the relative values 17 for the sharp triplets, 14.8 for the sextuplets, and 9.53 for the diffuse triplets. Probably he determined these values in a strong field, where, as we have seen, $\Delta\lambda$ does not increase so rapidly for the sextuplets and diffuse triplets as for the sharp triplets, and this probably accounts for the relatively lower value of $\frac{\Delta\lambda}{H\lambda^2}$ which he obtained for these lines.

I tried to determine whether the law of correspondence between homologous lines held for other members of the second subordinate series and for those of the first subordinate series, but the character of these lines is so bad that nothing definite can be said of them in regard to this point.

In the case of the cadmium line 4800.09 an attempt was made to measure the space between the lines in the outer pairs of the sextuplets in Plate XVI. The value obtained was 0.136 Ångström units, the value of $\Delta\lambda$ at the same time being 0.877 Å. U. This value is probably too large rather than too small, as the tendency is to overestimate the interval between such close lines. On the same plate the distance between the components of the inner pair was 0.255 Å. U.

A more remarkable line in the spectrum of magnesium is 3832.45. When in a magnetic field it consists of five (or possibly six) components, viz., a very strong central line or pair of lines, and two others on each side of it as shown in Plate XVII. The two faint extremes and the strong central line are polarized in a plane through the lines of force, the other pair in a plane normal to the lines of force. For a field strength of 28500 the separation between the faint extremes is 0.598 Å. U.; that between the pair polarized normal to the field, 0.228 Å. U.

The only other magnesium line for which any satisfactory measurements were obtained is 3838.4. This becomes a triplet of the usual type, rather diffuse. Its separation is 0.336 Å. U. for a field of 28500 units.

The zinc line 3075.99 becomes a very sharp triplet. Its separation is 0.300 Å. U. for a field of 26500.

The cadmium lines 2763.99 and 3403.7 seem not to be affected by the field at all, and 2980.8 shows only a broadening for a field of 28500. For the same field 3252.2 becomes a quadruplet with separation 0.488 Å. U. between its components polarized parallel to the field and 0.179 Å. U. between those polarized normal to the field.

The cadmium lines whose separation is given in the following table are all triplets in the magnetic field.

PLATE XVII

EFFECT OF A FIELD OF 25000 C. G. S. UNITS ON LINES OF CARBON, IRON, CALCIUM, ALUMINIUM, AND MAGNESIUM

CADMIUM.

Line	Strength of field			
	28500	27000	26400	20200
3081.03	0.770	.....	.....	.....
3261.17	0.402	.....	.....	.....
3466.33	.....	.....	.....	0.200
3610.66	0.410	.....	.....	.....
3613.04	.....	.....	0.320	.....
4415	.....	0.459	.....	.....

In the spectrum of nickel the lines 3424.2 and 3510.5 seem to be unaffected, while 3597.8, 3610.6, 3612.8 become quadruplets which are too faint on my plates to be measured under the microscope; but by comparison with neighboring lines it was estimated that the separation of their lateral components (in a field of 28300 units) was in each case rather greater than 0.4 Å. U. For the following lines, all triplets, the separation is given for a field of 28300 units.

NICKEL.

Line	$\Delta\lambda$	Line	$\Delta\lambda$
3370.6	0.353	3493.1	0.301
3381.7	0.318	3515.2	0.324
3414.9	0.374	3524.7	0.391
3446.4	0.350	3566.5	0.338
3458.6	0.292	3619.5	0.363
3461.8	0.377	3858.4	0.441
3472.7	0.467	5371.6	0.594

The spectrum of iron was the first studied in this investigation. A number of plates were first taken from wave-length 3500 to wave-length 4400. Of the lines in this region 3746.06, 3767.34, 3850.12, and 3888.67 seem to be unaffected, and 3722.72 and 3872.64 become quadruplets. Three lines, viz., 3587.13, 3733.47, and 3865.67, exhibit a peculiar state of polarization. Although they are triplets, the inner component is polarized along the lines of force and the outer components at right angles thereto, that is, just the reverse of the usual way.

This phenomenon was first observed for one of these lines by Becquerel and by Deslandres.[1] In comparing the separation of the lines between 3900 and 4450, it was at once observed that the lines could be broken up into two classes, in each of which the separation of the various lines was of the same magnitude. These two classes are identical with those for which Humphreys[2] found that the shift due to pressure was the same. On these plates the separation is very small in all cases owing to a weak field, and no accurate measurements were taken of the separation.

Plates have since been taken of other regions of the iron spectrum with much stronger fields. Four other quadruplets occur, viz., 3466.0, 3475.6, 3490.7, and 3587.13. In the case of the first two a Nicol's prism was used, which showed that in each case the inside pair of the components was polarized normal to the field, the outer pair along the field. The separation of the outer pair in the several cases is respectively 0.76, 0.50, 0.48, and 0.40 Å. U.

Only between wave-lengths 3600 and 4050 are the separations of iron lines determined for measured strength of field. This was accomplished, as noted above, by taking the spectrum of a spark between carbon terminals, the iron appearing as an impurity. The separation of these lines is given below for a field of 25000 units.

IRON.

Line	$\Delta\lambda$	Line	$\Delta\lambda$
3709.39	0.291	3820.59	0.236
3720.05	0.224	3826.03	0.226
3727.78	0.287	3860.06	0.311
3735.01	0.269	3886.43	0.309
3737.28	0.209	3895.80	0.292
3749.63	0.265	3899.85	0.307
3758.38	0.239	3920.41	0.311
3767.34	very small	3923.05	0.310
3815.99	0.239	3928.08	0.305
3930.45	0.311	4063.98	0.247
3968.	0.334	4071.90	0.154
4045.98	0.282		

[1] *Comptes Rendus*, April 4, 1898, p. 997. [2] This JOURNAL, **6**, 200, October 1897.

Some lines in the spectra of calcium, aluminium, and silicon also appeared as impurities in the carbon spectrum.

The aluminium line 3961 in a magnetic field is a triplet with separation 0.242 Å. U., while 3944 is a quadruplet with separation 0.279 between its components polarized parallel to the field and 0.138 between those polarized normal to the field.

The calcium line 3933 becomes a triplet whose separation is 0.222, 3968 a quadruplet whose components polarized parallel to the field are separated 0.282 Å. U., those normal to the field 0.144 Å. U.

The silicon line 3905 shows a separation of 0.209 Å. U. It is a triplet.

All the measurements given for the lines of aluminium, calcium, and silicion, were taken from the same plate, the field strength being 25000 units. On this same plate the carbon band between 3800 and 3890 shows no indication of magnetic effect.

The only titanium lines observed are 3658.3, 3759.4, 3761.4. All these become clean, sharp triplets. The separations for a field of 25000 units are respectively 0.272, 0.314, 0.247.

A few lines have been studied in the spectrum of mercury. In the following table the separation is given for a field of 24500 units.

MERCURY.

Line	$\Delta\lambda$	Line	$\Delta\lambda$
5460.97	0.756	4046.78	0.669
4078.05	0.493	3984.	0.350

All of these lines are diffuse, especially 5460.97, which may be of more complicated form than a triplet, as Blythswood and Marchant[1] found with the echelon spectroscope. The above value of $\Delta\lambda$ for this line agrees with that given by them as well as could be expected from the character of the line.

On one of my plates, taken of the spectrum of a spark between magnesium and cadmium, a group of air lines appears at

[1] *Phil. Mag.*, April 1900, p. 384.

about 4650. Although not clearly separated, owing to their diffuse character, some of them show unmistakable evidence of magnetic effect, and a few rough measurements were made to get an idea of the effect on air lines. For one the separation was estimated at 0.9 Å. U., for another at 0.4 Å. U., and for a third at 0.3 Å. U., while the rest could not be measured. These figures are not to be relied upon, as all the lines are quite diffuse.

A paper has recently been published by Zeeman,[1] in which he partially confirms Voigt's prediction by theory that for a triplet in a weak field the red component would be found stronger than the violet, but not separated so far from the central line. Although none of my plates were taken with a view to testing this theory, a search was constantly made for lines not symmetrical in separation. Many lines occurred where first measurements indicated asymmetry, but in most cases the definition was not good enough to warrant putting faith in the measurements, or else a more careful remeasurement showed that the first result was wrong. In the following instances, however, there really seems to be a difference in the separation on the two sides:

1. In the iron quadruplet 3466.0, the mean of the inner pair of components is a trifle farther toward the red than that of the outer pair.

2. In the triplets 4678.37 of cadmium and 4680.38 of zinc, the violet component is farther from the central line than the red component in a field of 24100 units, but both appear equally distant in a field of 26580 units.

3. In the sextuplets 4800.09 of cadmium and 4722.26 of zinc, the mean of the inner pair is a little farther toward the violet than the mean of the outer doubles in a field of 24100 units, but the group becomes symmetrical in a field of 26580 units.

As regards intensity, the above lines of cadmium and zinc as well as the lines 5086.06 of cadmium, 4810.71 of zinc and 5167.55, 5172.87, 5183.84 of magnesium all seem to have the red component stronger than the violet in weak fields. Also in weak fields the iron lines 3743.51, 3581.35, 3570.27, 3526.18,

[1] *Proc. Roy. Amsterdam Acad. Sci.*, Dec. 30, 1899.

and 3878.15 all seem to have the red component stronger than the violet. I have not observed any cases where the violet component is the stronger.

This investigation was begun in February 1898, in collaboration with Mr. Robert Earhart, under the supervision of Professor Ames, and was so continued until June of that year. During the following scholastic year, the writer continued the work, partly alone, partly with the assistance of other students, especially of Mr. J. F. Meyer and Mr. H. J. Lucke. During the present scholastic year he was assisted by Mr. Norton A. Kent, who will continue the work.

In conclusion I wish to express my obligations to Professors Rowland and Ames, and to Mr. Lewis E. Jewell, for their most valuable advice and encouragement.

Johns Hopkins University,
June 1900.

A NEW THEORY OF THE MILKY WAY.

By C. EASTON.

§ 1. My investigations on the apparent distribution of the stars in a part of the Milky Way, undertaken several years ago and published in the ASTROPHYSICAL JOURNAL, Vol. I, No. 3, March 1895,[1] seemed to indicate that it has a roughly annular structure. However, at the end of these articles I pointed out that there is nothing to prove that all parts of such a hypothetical ring — evidently very irregular in its details — are at the same distance from our Sun, nor even that it is a closed ring, independent of the central part of the galactic system. Moreover, Professor Seeliger, in an exhaustive discussion on the distribution of stars in space,[2] remarks that the conclusions reached in these articles do not necessarily apply to the entire Milky Way; he also thinks that the stellar accumulations of the Milky Way in different directions are probably at different distances.

I now propose to show that the annular theory of the Milky Way is in reality incompatible with the present state of our knowledge of the galactic phenomenon, and as there is little reason to hope that the great problem of the constitution of the visible universe will be definitively solved in the near future, I have added certain general considerations which seem to lead to a new theory of the structure of the Milky Way in space.

§ 2. If we assume that the actual form of the Milky Way corresponds with its apparent form: that of a ring surrounding us on all sides — what position must then be assigned to the Sun?

It does not seem to be situated near the center of the ring. In fact, a single glance at the Milky Way on a clear evening

[1] *Cf. A. N.*, 137, No. 3270.

[2] "Betrachtungen über die räumliche Vertheilung der Fixsterne." *Abh. d. k. bayer. Akademie d. Wiss.*, II Cl., XIX. Bd., III. Abth., 1898.

in August or September reveals a peculiarity which has apparently been given less importance than it merits: the great superiority in brightness of the Milky Way near *Aquila* as compared with that near *Monoceros*. It may be inferred from this that in general the stars are more numerous near the XVIIIth hour than near the VIth hour of right ascension.[1]

This unequal distribution of the stars of the Milky Way, not only in detail, but also for the two halves of the zone as compared with each other, when it is represented as divided along a line through *Crux* and *Cassiopeia*, is still more striking in the results of stellar gauges and enumerations. The mean result of William Herschel's gauges in the region of *Aquila* is 161.5 stars; in that of *Monoceros*, 82.5 stars. Similarly, Celoria, systematically counting the stars to about the eleventh magnitude in an equatorial band six degrees wide, has found 58,883 stars in the half of this band which is traversed by the Milky Way near XVIII^h, and only 43,822 in the opposite half.[2]

William Herschel's gauges and Celoria's enumerations include regions of very different areas and embrace very diverse stellar magnitudes; for this reason alone it is almost inadmissible that the divergence indicated can be the effect of a chance accumulation of stellar condensations near the constellation *Aquila*. Furthermore, the aspect of the sky, and the charts of the Milky Way where account has been taken of the general distribution of the galactic light in the various parts of the zone, seem to indicate a certain measure of gradation in the brightness. Encke, in his criticism of Struve's theory,[3] insists that if such a supposition is made—eccentric position of the Sun—values should be given for the stellar density intermediate between the maximum and minimum density; these values must then agree with a quantity determined by the eccentricity.

[1] *Cf.* PLASSMANN, *Mittheilungen der V. A. P.*, III, 1893, Berlin, Dümmler, 1893, p. 102; Easton, *Verslagen d. Kon. Akademie, Amsterdam*, 1897–8, p. 383.

[2] F. G. W. STRUVE, *Études d'astronomie stellaire*, 1847, note 75; G. Celoria, "Sopra alcuni scandagli del cielo," *Pubbl. del R. Osserv. di Brera*, **13**, 18.

[3] *A. N.*, **26**, 622.

The observations at our disposal at the present time are certainly not sufficiently numerous to permit such an investigation to be undertaken, and it is to be feared that the marked irregularities of a purely local character, in the structure and brightness of the Milky Way, will always stand in its way; but we may at least endeavor to indicate the principal features of the distribution of brightness in the Milky Way.

In his *Uranométrie générale*, Houzeau has enumerated thirty-three bright spots and regions of the Milky Way; he has also estimated their brightness. Although his method (indicated on page 15 of this work) cannot give results of great precision, we may certainly regard as "fairly bright" the spots which he estimates as of magnitude 5–6, and as "bright" those which he estimates as 5 or 4–5. By dividing the entire Milky Way into halves by a line passing through *Crux* and *Cassiopeia*, I find in the half which contains *Monoceros* four or five fairly bright spots and not a single bright spot; in the half which contains *Aquila* I find seven or eight fairly bright spots and seven bright spots. The conclusion is the same as for the gauges of Herschel and Celoria.

Considering only the zone comprised between $-45°$ and $+45°$ I find two fairly bright spots and no bright spot near VI^h, as against six fairly bright spots and five bright spots near $XVIII^h$.

It follows that these apparent accumulations are comparatively most numerous in the region of *Aquila*, between $-45°$ and $+45°$, and that they are least numerous in the opposite zone, near *Monoceros*. From this point of view these two zones, each embracing a quarter of the circumference, are in the ratio of 5.5 to 1, while for the corresponding *halves* of the Milky Way, the ratio is 2.8 to 1. On my chart of the Milky Way it may be seen that the general brightness of the Milky Way diminishes pretty gradually from *Cygnus* to *Cassiopeia;* the same thing occurs between *Ara* and *Navis* in the southern hemisphere. But the gradation is very incomplete: between α *Persei* and α *Aurigae*, for example, the brightness of the Milky Way is much less marked than between α and θ *Aurigae*.

Gould remarks (*Uranometria Argentina*, p. 370) in speaking of the Milky Way in the southern hemisphere: "Its brightest portion is unquestionably in *Sagittarius*, that in *Carina* being slightly inferior to this as regards intrinsic brilliancy, although far more magnificent and impressive on account of the great number of bright stars with which it is spangled."

After having indicated this characteristic feature in the general distribution of brightness in the Milky Way, we may attack the problem from a different side.

§ 3. It is easy to imagine the aspect of the heavens, for each of the typical positions which may be assigned to the Sun, from the interior of the Milky Way considered as a stellar ring.

We may then distinguish the five following cases:

a. The Sun occupies the center of the ring. In this case the Milky Way will appear as a more or less irregular luminous band, in which the irregularities in the distribution of the stars (dark and bright spots, richness in bright stars, unequal width of the zone) are not grouped systematically with reference to any given point of the circumference.

b. The Sun occupies an eccentric position.—The brightness of the Milky Way is less marked near 180° than near 0°, rapidly increases up to a point beyond 90° (270°), then more gradually or insensibly to about 0°. Between 180° and 90° there are many bright stars; these become less numerous as the zero point is approached. The width of the Milky Way is greater near 180° than near 90° (Fig. 1).

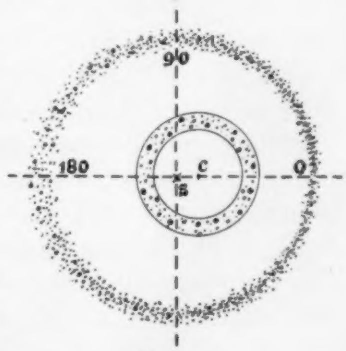


FIG. 1.

c. The Sun is situated on the inner edge of the ring.—The difference in the width of the Milky Way near 0° and near 180° is much more marked; the maximum of faint stars occurs between 0° and 90°, that of the bright stars at about 90°. Near 180° the Milky Way is very broad, vague, and very faint; whether the galactic light

in this part of the sky is still even perceptible will depend on the thickness of the ring (Fig. 2).

d. The Sun is situated in the body of the ring.—Towards 180° no trace of the Milky Way will be visible, nor will the bright stars be very numerous in that region. Between 180° and 90° a faint galactic glow commences to appear, which increases pretty rapidly toward 90°; the bright stars also become more numerous and are seen in greater number beyond 90°. At first scattered, between 180° and 90°, over nearly a semi-circumference, the galactic glow grows narrower and narrower, becoming at the same time more brilliant, and the brightness attains its maximum between 90° and 0°. The Milky Way is narrowest near 0° (Fig. 3).

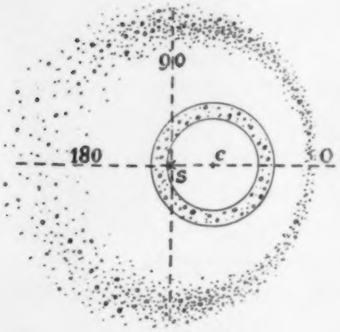


FIG. 2.

e. The Sun is situated on the outer edge of the ring.—The phenomenon which I have just described under *d* can hardly be called "Milky Way," but in this last case (*e*) nothing is seen but a spindle-shaped nebulous glow occupying less than half a great circle, with a long and narrow condensation. An immense mass of stars, of a somewhat nebulous appearance, and an empty sky surrounding them.

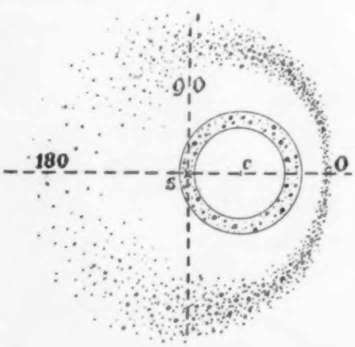


FIG. 3.

§ 4. The general aspect of the Milky Way, as it appears to us, and the result of stellar gauges and enumerations to which reference has already been made, would correspond very well with case *b* if it were not for an important exception regarding the *width* of the zone.

The limits of the Milky Way are so vague that it is impossible to measure the width exactly on the drawings. According

to the charts by Boeddicker and myself, the Milky Way is a little wider near *Monoceros* than near *Aquila*, taking into account the separate branches; according to Gould's chart, on the contrary, it is a little wider near XVIII^h.[1] However this may be, in the theory of a galactic ring one would expect to find a very striking difference *in width*, as the difference between the *brightness* of the opposite regions is so evident.

But we possess a surer means of measuring the width of the Milky Way, independently of the optical phenomenon, *i. e.*, the width of the zone where the stellar density is higher than the average. In discussing the results of his stellar enumerations, Celoria (*loc. cit.*, tav. V.) gives diagrams of the stellar density in an equatorial zone 6° wide, (1) for the stars of Argelander's *Durchmusterung*, (2) for the stars to about the eleventh magnitude, counted at Milan, (3) for the stars comprised in W. Herschel's gauges between +20° and —20°, corresponding to Celoria's zone. By measuring the horizontal projection of the curves which rise above the mean, the following results are obtained:

a. When only the stars of the *DM*. are considered (magnitude about 0–9.5), the Milky Way is about 5° wider near VI^h than near XVIII^h.

b. For Celoria's stars, on the contrary (magnitude about 0–11), the Milky Way is about 18° wider near XVIII^h than near VI^h.

c. The gauges of W. Herschel (magnitude 0–14?) similarly indicate that the Milky Way is about 4° or 5° wider near XVIII^h than near VI^h.

Thus, *for the faint stars taken as a whole, the Milky Way is widest in its brightest part*, and at least for Herschel's gauges, this certainly cannot be explained by local causes.

This result is evidently not in harmony with case *b*, § 3, which is nevertheless the only supposition that seems to correspond with the appearance of the sky and the result of the star gauges,

[1] BOEDDICKER, *The Milky Way*, London, Longmans, and New York, Scribner, 1892; Easton, *La Voie lactée*, Paris, Gauthier-Villars, 1893; Gould, *Uranometria Argentina*, 1879.

in the theory of an annular Milky Way. This theory thus leads us to the following dilemma: the galactic ring is a ring the chance irregularities of which are markedly, one might even say systematically, grouped with reference to a certain part of the circumference—which is extremely improbable—or else it broadens considerably in one half of the circumference, which appears no more probable.[1]

§ 5. May it not be that the anomaly which we have just noted in the width of the Milky Way near XVIII^h, as compared with the opposite part of the zone, is due to the fact that the ring is really double, over nearly one half of its circumference, as it is shown in the old drawings of the Milky Way?

At first sight it would seem strange that, for one of the halves of the ring, there should exist, not a division, but an actual duplication—for twice as many stars are counted on the "two branch" (*Aquila*) side as on the opposite side—and especially since the classic division of the galactic zone into two *distinct and separate* branches, between *Cygnus* and *Centaurus*, no more exists than the single band between *Cassiopeia*, *Monoceros*, and *Crux;* this follows from all the evidence of the modern charts and photographs of the Milky Way. On the one hand the northern (secondary) branch of the Milky Way is not a single and continuous stream, and the part between δ *Cygni* and γ *Ophiuchi* cannot be regarded as the continuation of the luminous regions toward *Scorpius* and δ *Ophiuchi;* and on the other hand the ramifications properly so-called seem to be even more numerous in the part which was formerly regarded as single than in the "double" part of the Milky Way.

With a little good will it is possible, however, to trace a zone, starting from ϵ *Cassiopeiae*, through γ and δ *Cygni*, ϵ *Aquilae*,

[1] Sir John Herschel (*Outlines of Astronomy*, § 788) assigned to the Sun an eccentric position in the Milky Way on the side nearest the southern parts of the zone, on account of their great brightness and their better defined boundaries. Proctor has followed the same reasoning for the construction of his spiral (*Monthly Notices*, **30**, 50). From what precedes one would infer, on the contrary, that the Sun is, in general, nearer the vague and faintly luminous parts of the Milky Way. Proctor's "spiral," moreover, explains none of the principal features of the galactic phenomenon, although it led its author to make interesting remarks.

θ Ophiuchi, and terminating at *α Centauri*, in which the galactic light is in general more brilliant than between this zone and the principal branch of the Milky Way. It is even possible to regard the faintly luminous streams between *ζ Persei*, *δ Orionis*, and *ε Canis Majoris* as the continuation of this "secondary" Milky Way, and also to connect it with "the belt of bright stars" of John Herschel and Gould, extending through *Taurus*, *Orion*, *Crux*, *Scorpius*, etc. We should thus have an indication of two principal planes, in which are grouped both the bright and the faint stars of the Milky Way.

It may be remarked that Celoria (*loc. cit.*, 42; *cf.* Gould, *loc. cit.*, 381) by a process of reasoning different from that which has led us to reject the theory of a single ring, reaches the conclusion that there exist *two galactic rings*, inclined to each other at an angle of 19° or 20°, one of which contains principally the fainter stars, the other the bright stars. Celoria is unable to decide whether these two rings coincide at the point where they appear to touch. The principal ring, composed particularly of faint stars (*i. e.*, distant stars, in Celoria's hypothesis) would be projected on the sphere in a great circle traversing *Sagitta*, *Auriga*, *Monoceros*, *Scutum;* the secondary ring would include the branch of the Milky Way in *Ophiuchus*, the branches in *Orion*, the *Hyades*, the *Pleiades*, and the belt of bright stars.

§ 6. Assuming that the belt of bright stars and the secondary branch of the Milky Way (which seems to be the cause of the incompatibility between the aspect of the Milky Way and the annular theory) are due to the same cause: the existence of a *secondary galactic ring*, it will be noticed that the belt and the secondary branch are, so to speak, complementary; the bright stars are numerous where the secondary Milky Way is very faint—*Taurus*, *Orion*, etc.—and, on the contrary, the belt of bright stars is almost wholly effaced where the secondary branch of the Milky Way is fairly bright—*Ophiuchus*, *Cygnus*. Thus, for this secondary galactic ring, the position of the Sun should correspond with case *c*, § 3—and hence the secondary ring must be *much smaller* than the principal ring—while this position will

be intermediate between cases *b* and *a* so far as the principal ring is concerned.

If now we place the center of the secondary ring at some distance from the center of the principal ring, and outside of the principal plane, the Sun being near the line of intersection of the two planes *p I p'* (Fig. 4*a*), the *general features* of the galactic

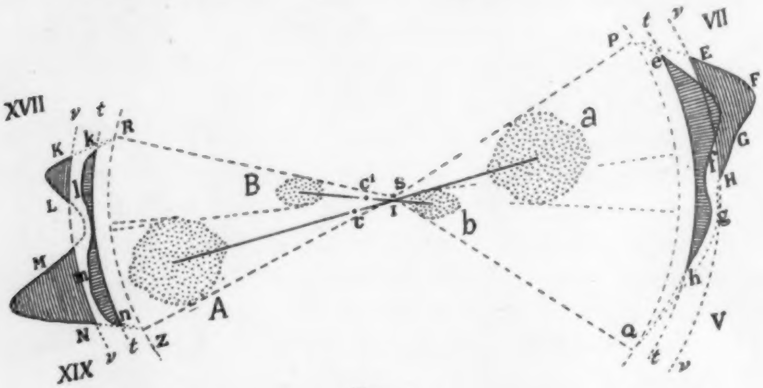


FIG. 4.

phenomenon are fairly well explained by what we may call Celoria's modified theory.

In Fig. 4 let *c* and c^1 be the centers of the two galactic rings, whose equatorial sections are *A*, *a* and *B*, *b;* let *I* be the projection of the line of intersection of the two galactic planes, and *S* the position of the Sun; the angle *PSQ* will be greater than the angle *RSZ.* For the stars of the *DM.*, *a* and *b* unite to produce a density greater than the average near VI^h, because stars of various magnitudes are mingled together in the Milky Way, and because, consequently, there is also a surplus of bright stars near *a*, although the great majority of the stars at *a* (*i. e.*, of the outer galactic ring) escape observation, which nevertheless includes the greater part of the stars of *b*, the interior ring. All that is above the average density (theoretical Milky Way)[1] for the stars of the *DM.* is indicated by the curve *efgh.* But Herschel's

[1] The *optical* Milky Way, which is a rather complex and purely subjective phenomenon (*cf.* my *Milky Way*, Introduction, p. 12), thus resembles a theoretical Milky Way composed of a great number of telescopic stars fainter than magnitude 9.5.

gauges contain the greater part of the faint stars included in *a*, while in the direction of *b* the number of stars increases in a much less rapid proportion; in fact, hardly increases at all beyond a certain telescopic power. The Milky Way for Herschel's stars will be indicated by the curve *EFGH*, less extended than the curve *efgh*. Near XVIII^h, on the contrary, especially on account of the distance of *B* as compared with *b*, the stars of the interior ring contribute in an important degree toward the formation of the Milky Way, and this narrowing of the Milky Way in proportion as the number of telescopic stars increases will be less sensible; for the telescopic stars the Milky Way may be as broad as, or even broader than the zone near VI^h. The density of the Milky Way in the direction of XVIII^h will be greater on account of the greater distance; therefore it will also be more brilliant.

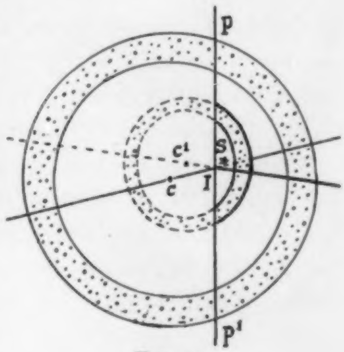


FIG. 4*a*.

The Sun cannot be very far from the line of intersection of these two principal planes of the Milky Way, which terminate in *Cassiopeia* and *Crux*, a distance of about 180°. This forces us to place the center of the secondary (interior) ring rather distant from the plane of the principal ring, which appears to be a weakness in this theory. If we could assume the existence of an actual condensation of stars in the direction of *B* (see Fig. 4), this would explain the brilliancy of the Milky Way in the direction of *Cygnus* and *Ophiuchus*, and we would be free to make the interior ring still smaller and to bring the center c^1 nearer the point *I*. We shall see in what follows that there in fact seems to be a plausible reason for making such an assumption.

§ 7. However, all that has been learned regarding the constitution of the Milky Way since the ingenious investigations of the Italian astronomer (Celoria) — more thorough studies of the Milky Way with the naked eye, structure of galactic clouds revealed

by photography, etc. — forces us to admit that the Milky Way cannot be composed of two distinct, uninterrupted rings, as Celoria believed ("due anelli distinti, nè mai interrotti nel loro corso," *loc. cit.*, p. 41). In reality, the structure of the Milky Way, even in its principal features, must be much more complicated.

Nevertheless this fact does not require us to reject all the considerations set forth in the above paragraphs. On the contrary, although the irregularity of the Milky Way is evident enough so far as the details of the zone are concerned, and although the situation of our Sun makes it very difficult for us to discover a definitive arrangement of the stars and stellar groups which surround us on all sides in the plane of the Milky Way — there are nevertheless indications that regularity is not altogether lacking in the distribution of the galactic stars; evidence that, so to speak, our stellar system possesses a certain degree of organization.

Let us first pass in review these indications, and subsequently consider the modifications which can advantageously be made in the theory stated in § 6.

I need not here dwell upon the fact — first pointed out by William Herschel (although contradictory to his first hypothesis of the uniform distribution of all stars in space): the reality of the clustering tendency which is seen in certain parts of the heavens. While in certain regions of space the distances between stars are enormous and the stars are quite alone or grouped only in binary and triple systems, etc., there are other regions where the original matter has condensed in star clusters, and still others where accumulations of stars of different magnitudes occupy very extensive regions of celestial space. Bauschinger and Sidney Waters have pointed out the correlation between these last two phenomena, *i. e.*, that star clusters for the most part follow the ramifications of the Milky Way. The same is true, it would appear, of diffused nebulosities.

It nevertheless does not follow that there must exist an organic connection between the stellar groups of the Milky Way,

nor that the stars which are clustered together, and those which are relatively isolated, should form two independent systems.

§ 9. If it is no longer possible to regard the stellar accumulations of the Milky Way, taken as a whole, as a ring, or even as two interlacing rings, the aspect of the Milky Way by no means excludes the existence of annular segments or of streams or strata of stars.

The majority of the stars seem to be grouped in two principal planes. This conclusion, developed in Celoria's investigations, is found in slightly different form in the writings of John Herschel and Gould ("belt of bright stars," "cluster of bright stars." *Cape Observations*, 1847, § 321; *Uran. Argent.*, 368). Ristenpart states that the principal plane of the Milky Way is not a broken plane, but is composed of two planes slightly inclined to each other.[1] Struve, who preferred a "broken plane," did not exclude the idea that "the most condensed layer of stars lies in two planes" (*Et. d'astr. stell.*, 1847, p. 82).

Such an arrangement of the greater part of the stars in two planes, slightly inclined to each other, would appear hardly compatible with the idea of a purely fortuitous distribution of the stars in the galactic layer.

§ 10. The aspect of the Milky Way does not correspond to the projection of agglomerations distributed by chance in space, which would rather produce series of superposed spots, for the most part condensed toward the center, and in general more numerous and more brilliant as the galactic equator is approached, without characteristic differences in the various portions of the zone.

On the contrary, in many parts of its course the Milky Way is composed principally of stellar beds or streams, frequently irregular, it is true, but of a character which differs essentially from the appearance which would be produced by the projection of irregular clusters situated at different distances (*cf.* the photographs of the regions surrounding *Crux*, *Scorpius*, *ε Cygni*, *δ Cephei*, etc.)

[1] *Veröffentl. grhz. Sternw. Karlsruhe*, 1892, p. 67.

Furthermore, it follows from even a superficial study of the aspect of the Milky Way that the constitution of the belt exhibits characteristic differences when extensive and widely separated parts are compared among themselves. Relatively uniform regions immediately follow flocculent regions; here series of spots are seen, there ramifications extending over enormous distances. As examples we may cite the Milky Way in *Sagittarius* and *Scutum*, in *Cygnus* and *Lacerta*, in *Cassiopeia* and *Perseus*.

It is also a remarkable fact that the gradation of the light in passing from the edges toward the middle of the belt is very different in different parts of the Milky Way. Thus, in the principal branch which passes through α *Aquilae*, the brightness decreases gradually from the inner edge toward the outer boundary, while in the secondary branch (from *Lupus* to *Camelopardus*) the luminosity is much more uniform. The region between γ *Sagittae* and ν, δ, and β *Cygni* is an exception: the principal branch here appears vague and dull, and a great bright spot extends from γ to β *Cygni*, encroaching a little on the dark interval.[1]

§ 11. In addition to these characteristic features there is the tendency to form streams and branches. Sir John Herschel, who was perfectly acquainted with the telescopic structure of the Milky Way, called attention to the fact that in the southern hemisphere he saw a series of star clusters distributed along a luminous band of the Milky Way, while no cluster was visible in the dark interval between the galactic branches.[2] He speaks elsewhere of fainter and less clearly defined streams and again of the tendency of the secondary streams to unite with the principal stream.[3]

Telescopic observation suggested to him still more precise ideas. "In some [regions], for instance," he remarks, "extremely minute stars, though never altogether wanting, occur in numbers so moderate as to lead us irresistibly to the conclusion that in

[1] GOULD, *loc. cit.*, 381; Easton, *Voie lactée*, Description, pp. 41, 47.

[2] J. HERSCHEL, *Cape Observations*, 1847, p. 387; *cf.* Sidney Waters, *Monthly Notices R. A. S.*, LIV.

[3] *Ibid.*, p. 386.

these regions we see *fairly through* the starry stratum, since it is impossible otherwise (supposing their light not intercepted) that the numbers of the smaller magnitudes should not go on continually increasing *ad infinitum*. . . . In other regions we are presented with the phenomenon of an almost uniform degree of brightness of the individual stars, accompanied with a very even distribution of them over the ground of the heavens, both the larger and the smaller magnitudes being strikingly deficient. In such cases it is equally impossible not to perceive that we are looking *through* a sheet of stars nearly of a size, and of no great thickness compared with the distance which separates them from us. Were it otherwise we should be driven to suppose the more distant stars uniformly the larger, so as to compensate by their greater intrinsic brightness for their greater distance, a supposition contrary to all probability. In others again, and that not infrequently, we are presented with a double phenomenon of the same kind, viz., a tissue as it were of large stars spread over another of very small ones, the intermediate magnitudes being wanting. The conclusion here seems equally evident that in such cases we look through two sidereal sheets separated by a starless interval."[1]

In several parts of the Milky Way one notices (not on the photographs, which are incomparable for the study of the structure of the details, but do not bring out the greater features of the galactic image) what Dr. Boeddicker calls "the tendency to duplication;" this tendency is particularly noticeable in *Cassiopeia* and *Perseus*.[2] It would seem very difficult to reconcile this phenomenon with the absence of all structure in the Milky Way.[3]

[1] *Outlines*, § 797.

[2] BOEDDICKER, *Monthly Notices R. A. S.*, L, No. 1; Easton, *Voie lactée*, Plate III and Description, p. 49.

[3] I cannot here enter into a discussion of the much disputed question of the reality of "star drifts" (Proctor), ellipses and wreaths (Holden), lines of stars (Ranyard, Backhouse), etc.

It is equally impossible in this necessarily limited discussion to consider the interesting investigations which treat of the relation of the galactic plane to the distribution of the various spectral types, Wolf-Rayet stars, new stars, etc., by Dunér, Pickering, McClean, Campbell, Kapteyn, and others, nor the investigations on the distribution of nebulæ, the constitution of the Magellanic clouds, etc.

§ 12. The dark spots and bands in the Milky Way particularly merit our attention. A well-known argument of Sir John Herschel is drawn from the fairly regular dark spots; "When we see, as in the coal-sack, a sharply-defined oval space free from stars, insulated in the midst of a uniform band of not much more than twice its breadth, it would seem much less probable that a conical or tubular hollow traverses the whole of a starry stratum, continuously extended from the eye outwards, than that a *distant* mass of comparatively moderate thickness should be simply perforated from side to side, or that an oval vacuity should be seen foreshortened in a *distant* foreshortened area, not really exceeding two or three times its own breadth."[1]

The "coal-sack" near the Southern Cross is better known, but is perhaps not more remarkable than certain other similar openings in the Milky Way. I cite in the first place the elliptical spot situated half way between *α Cygni* and *α Cephei*.[2] Notice also the curious little black spots, which so well produce the effect described by Herschel as an "oval vacuity," between *α* and *f Cygni*, on Max Wolf's photographs.[3] As opposed to Sir John Herschel's argument the objection has been raised that the proximity of the dark and bright spots in the Milky Way does not exclude the possibility that in this direction the cosmical matter may be greatly extended in the line of sight, since the probability of the existence of apertures in an accumulation of a limited number of stars does not depend upon the dimensions in the line of sight.[4] A popular objection would be that portions of the sky can always be seen through the foliage of a tree. I think there is a slight error in this interpretation of Sir John Herschel's idea. Two or three leaves form as much of a screen as a thousand leaves, while a thousand stars form a luminous accumulation as compared with a region where the

[1] *Outlines*, § 792.

[2] No. XVII of my catalogue; see also Heis, *Atlas coel. novus*, 1872, and *cf.* Oehl, in *Gruithuisen's Naturw. Astron. Jahrbuch*, IX, 1846.

[3] Reproduced in *Knowledge*, October and December 1891, in Schweiger-Lerchenfeld's *Atlas der Himmelskunde*, and elsewhere.

[4] SEELIGER, *loc. cit.*, 628.

stars are few, and it is precisely this relatively homogeneous character of regions surrounding the "coal-sacks" which suggests the idea of a perforated band. It is true that the limits of these dark spots are not so well defined as Herschel supposed them. (See the "coal-sack" on Russell's photographs and on those of Pickering in the publications of the Henry Draper Memorial); nevertheless, in my opinion, the degree of definition of the edges of these spots and the uniformity in brightness of the surrounding regions are sufficient to sustain Herschel's argument. It is a question of judgment. To take a definite case, it seems to me that the appearance of the regions surrounding the small black spots in the neighborhood of f^2 *Cygni* and θ *Ophiuchi* on the photographs of Wolf and Barnard can only be explained as due to actual holes in a comparatively thin layer of stars.

A similar argument is furnished by the dark bands and fissures in certain parts of the Milky Way. Maunder[1] has already pointed out that these dark lanes are most easily explained as actual openings in the star clouds of the Milky Way. But it is particularly in that part of the Milky Way lying on the boundaries of *Ophiuchus* and *Scorpius* that a magnificent photograph taken by Professor Barnard on June 21, 1895 reveals, between ω *Ophiuchi* and *Antares*, streams separated by dark intervals, which strongly suggest the existence of actual stellar strata, the thickness of which is small as compared with their distance from us (see Plate XI).[2]

§13. If the considerations developed in the preceding paragraphs render probable the existence of extensive but comparatively thin strata or streams of stars—which may be projected upon each other in certain parts of the Milky Way—there are also reasons to believe that the various portions of the Milky Way are not all at the same distance from us; reasons additional to those based upon the conclusions which may be drawn from Celoria's investigations (§§ 5 and 6).

[1] *Knowledge*, Feb. 1895, p. 37.

[2] See E. E. BARNARD, this JOURNAL, March 1899, on the very dark openings in the dark bands.

A minute study of the Milky Way in the southern hemisphere led Sir John Herschel to the conclusion that this part of the zone is composed of various portions situated at different distances (*Cape Observations*, § 321). In certain regions he believed that his telescope led his view across two stellar strata, separated by an interval void of stars. Elsewhere he describes the space revealed to him by his telescope as a cone filled with stars for a limitless distance in the line of sight. In this case, however, his reasoning would not appear to be well founded, as has already been indicated by Proctor.[1] But the argument based on the lateral branches of the Milky Way — in the northern hemisphere they are mentioned by Heis (*Draco*), Gould (*Orion*), Easton (*Auriga, Lynx*), and particularly by Boeddicker — would appear to have more weight: "Neither can we without obvious improbability refuse to admit that the long lateral offsets which at so many places quit the main stream and run out to great distances, are either planes seen edgeways, or the convexities of curved surfaces viewed tangentially, rather than cylindrical or columnar excrescences bristling up obliquely from the general level."[2]

It is evident that these lateral branches, which frequently extend to a considerable distance from the galactic equator, are in general much more easily explained by supposing that they extend on this side, and not beyond the principal branch of the Milky Way. Thus some portions of the Milky Way would be comparatively near us.

Another consideration, which is perhaps even more important, is the following. In certain parts of the Milky Way the galactic image, with its bright and dark spots, would appear to be outlined by the distribution of the stars of Argelander's last class.[3] On the other hand, Professor Seeliger has shown[4], by a comparison of the number of stars in the two *Durchmusterungen* with those of William and John Herschel's gauges, that this is not

[1] *Intellectual Observer*, August 1867. [2] *Outlines*, § 792.

[3] EASTON, *Verslagen Kon. Akademie Amsterdam*, 1894–5, p. 187.

[4] *Loc. cit.* 626.

the case for the whole galactic zone. However, there are some regions where even the naked-eye stars are evidently correlated with the distribution of the galactic light, as follows from a simple comparison of the Bonn charts with the most detailed photographs and charts of the Milky Way. I cite especially the luminous spot between α and *A Cygni*, and the northern part of the great spot $\gamma-\beta$ *Cygni*.[1] Unless we suppose gigantic stellar accumulations to exist at this point we are forced to admit that this part of the Milky Way is much nearer to us than the average.

Although it appears from the beautiful investigations of Professor J. C. Kapteyn[2] that the mean distance of stars of a given magnitude is much greater in the Milky Way than outside of this zone, the branches which start from the central part of the Milky Way and include the *Pleiades* and several bright stars in *Orion* seem also to support the conclusion that in certain parts of the Milky Way the small stars are at distances comparable with that of the bright stars.

§14. The galactic region in *Cygnus*, referred to in the preceding paragraph, is very remarkable and in fact quite exceptional as regards its brightness and its situation in the zone.

If we omit questions of detail, that which strikes us most forcibly in studying the aspect of the Milky Way in the northern hemisphere is the fact that the principal branch is exceedingly faint in *Perseus*, and that the secondary branch, very faint elsewhere, has a remarkably brilliant portion in *Cygnus*, between β and γ, about 90° from the sparse region in *Perseus*. These two characteristic features are evident not only in the distribution of stars of magnitudes 6–9.5[3] but even in the grouping of stars of magnitudes 0–6.[4]

The brilliant region between β and γ *Cygni* is connected—as the photographs abundantly attest—with a smaller but equally bright spot between α and *A* (68) *Cygni*, which in its turn is

[1] *Cf. Ast. Nach.*, No. 3270. [2] *Verslagen Kon. Akademie Amsterdam*, 1892–3.

[3] PLASSMANN, *loc. cit.*

[4] SCHIAPARELLI, "Sulla distribuzione," *Pubbl. Brera*, XXXIV, 1889.

connected with another less brilliant spot, between ρ and π *Cygni*, which is continued by a luminous stream, slightly inclined to the galactic equator, to a kind of knot near η and β *Cassiopeiae*, where the Milky Way divides; in part these branches lose their brightness rather abruptly at the altitude of γ *Persei*. Between *o Cygni*, *a Cephei* and η *Cassiopeiae* a much fainter zone extends, which shows a tendency to reunite with the principal branch.[1] Almost the entire region described here, with a few branches toward *Draco* and *Ursa Major*, and the fairly bright part between β *Cygni* and γ *Ophiuchi*, produce somewhat the impression of an immense appendage of the principal branch, with which the bright region between δ *Cephei* and *a Cygni* would appear to be closely connected; while the series of small luminous spots between γ *Sagittae* and ν *Aquilae* do not seem to be independent of the luminous region north of β *Cygni*.

I insist upon the exceptional position of this spot, or rather conglomeration of bright spots, between β and γ *Cygni*. It lies in the midst of a series of luminous spots and streams between ν *Aquilae* (the series which commences in *Sagittarius* appears to be related to this one) and χ *Persei*, but it is the only one — with the possible exception of the spot at *a–A Cygni*, just on the galactic equator — which is not situated on the inner edge of the principal branch of the Milky Way, but in the secondary zone, not far from the galactic axis. This is, moreover, the only very bright region which occurs in the "secondary zone" (§5), and the only place where this zone is brighter than the principal branch.

This region between *A* (68) and β *Cygni* is richer in stars than any other zone in Argelander's *Durchmusterung*. As for the fainter stars, William Herschel found here one of the maxima of his gauges: 588 stars per telescopic field; Th. Epstein[2] counted near ϕ *Cygni* 600 stars to the eleventh or twelfth magnitude in an area which on an average would contain only 140.[3]

[1] EASTON, *Voie lactée;* Boeddicker, *Milky Way*. [2] See PLASSMANN, *loc. cit.*

[3] The estimate of the brightness of this region in Houzeau's *Uranométrie*, p. 17, is certainly too small.

In the southern hemisphere brighter spots occur, notably that in *Scutum* and near γ and μ *Sagittarii*. But the spot at β–γ *Cygni* is larger than all these others combined. Furthermore, the brightness of the southern region in *Sagittarius* is particularly striking, on account of the contrast between the small bright spots and the very dark regions which separate them; the great bright spot in *Cygnus*, on the contrary, has no definite boundaries and is surrounded by a rather luminous region of the Milky Way.

As for the very faint region in *Perseus*, it is remarkable in that it is situated northeast of the tortuous part of the Milky Way, which, in *Auriga*, deviates considerably from the galactic axis. It may also be remarked that the "zone of nebulae" on Sidney Waters' chart approaches the Milky Way at this same place.

§15. This brilliant and relatively independent region in *Cygnus* which, moreover, is certainly connected with the other parts of the Milky Way, occurs in a part of the sky where, in the provisional supposition made in paragraph 6, the explanation of the general features of the Milky Way would be much simplified if it were permissible to assume the existence of an important stellar condensation in this direction. On the other hand—though this is perhaps a chance coincidence—the center of the secondary accumulation of which our Sun is a part would be situated, according to Professor Kapteyn's investigations, not far from this region.[1]

May not the bright region in *Cygnus* be the *central accumulation of the Milky Way?* If this were the case the general features and many characteristic details of the galactic phenomenon might be easily explained.

Fig. 5 gives an approximate representation of the Milky Way between γ *Ophiuchi* and β *Cassiopeiae* (*cf.* my chart of the Milky Way, Plate IV). Fig. 6 is based upon the two rings of the provisional theory stated in §6. In order to simplify the drawing I have left unbroken the exterior ring $RR'R''$ (principal

[1] KAPTEYN, *Verslagen Kon. Akademie Amsterdam*, 1892–3, p. 129.

branch of the Milky Way) except the very faint part between *R* and *R''* (*Perseus*). As for the interior ring, it must divide into at least three principal parts:

A, the bright part between γ *Ophiuchi* and *Cassiopeia*, considered as an appendage of the principal ring, in accordance with what has been stated in the preceding paragraph.

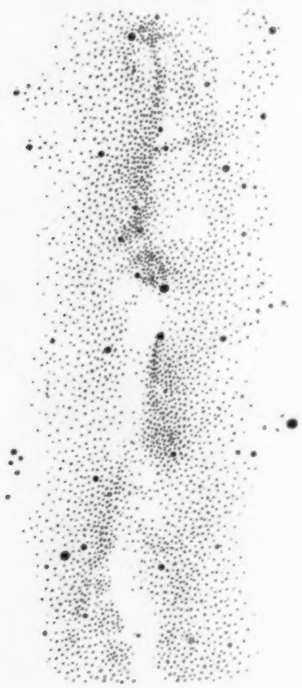


FIG. 5.

B, the secondary branch in *Serpens, Scorpius, Lupus;* closely related rather to the principal branch in this region than to the secondary branch in *Ophiuchus* (north of γ) and *Cygnus*.

C, the belt of bright stars, projected upon a very faint nebulosity.

Certain details between *Aquila* and *Cassiopeia*, the "luminous bridges" which are projected upón the "rift" between the two branches, etc., have been inserted from the galactic chart of this region (Fig. 5).

The representation of the Milky Way thus obtained curiously resembles the spiral nebulae, of which Dr. Isaac Roberts has given such beautiful photographs.[1] To facilitate the comparison I have sketched in Fig. 7 the principal features of the nebula *M. 74 Piscium*. It is unnecessary to remark that the distortion of the spiral in Fig. 6 is due to the preconceived idea of the two rings (in reality the cluster in *Cygnus*, and not the Sun, is at the center of the system).

From what precedes it follows, furthermore, that the convolutions of this "galactic spiral" would not be situated in a single plane, but principally in two planes forming an angle of about 20°.

[1] *A Selection of Photographs*, London, 1894.

It would be easy to push the comparison further[1] and to find in it a plausible explanation of many features of the galaxy. But I confine myself here to pointing out how easily this theory explains the luminous streams between the two branches of the Milky Way, in *Sagittarius* and *Cassiopeia;* the anomalous brightness of the secondary branch near *Cygnus;* the dark spaces surrounded by luminous streams between *α Cygni* and *β Cassiopeiae*, etc.; the "lateral offsets" of the Milky Way; the connection of the clusters and the bright stars in *Taurus* and *Orion* with the nebulosities related to the Milky Way; the very faint region in *Perseus*, etc.—while retaining the advantages offered by the annular segments. I wish to insist upon the fact that Fig. 6 ***does not pretend to give an even approximate representation of the Milky Way***, seen from a point in space situated on its axis. It only indicates in a general way how the stellar accumulations of the Milky Way might be distributed so as to produce the galactic phenomenon, in its general structure and its principal details, as we observe it.

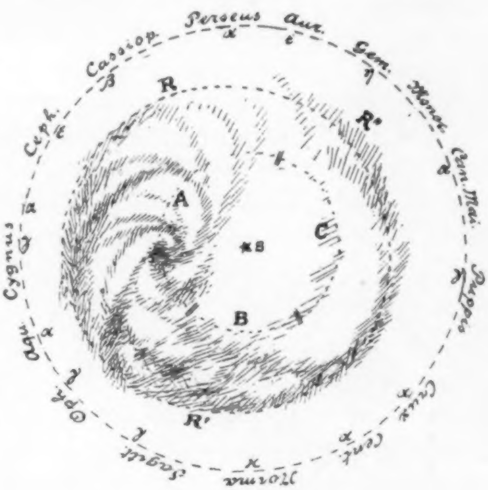


Fig. 6.

[1] Arguments based upon analogy are always dangerous. It is nevertheless permissible to point out here that the most recent observations and photographs show that the spiral is a much commoner form in the structure of nebulae than has hitherto been supposed. Only recently it has been recognized in the supposedly oval nebula of *Andromeda* (*cf.* Scheiner, *Astr. Nach.*, Bd. 148, No. 3549), and Professor J. E. Keeler sums up as follows the results of his investigations on the structure of nebulae (*Astr. Nach.*, Bd. 150, No. 3601): "If, then, numerous exceptions prove that spirality in nebulae is not a universal law, it may perhaps be regarded as the usual or normal accompaniment of contraction in cosmical masses. . . . ."

§16. It is possible that our Sun and the group of stars which, according to the investigations of Schiaparelli, Gould, and Kapteyn, form with it a secondary system in the great galactic system, may be only one of the clusters lost in the convolutions of the galactic spiral. But it seems to me simpler to suppose that what appears to be a "solar cluster" is the expression of the central condensation of the galactic system itself, composed for the most part of suns comparable with our own (and which would thus embrace most of the bright stars to the ninth or tenth magnitude). The distance of the galactic streams and convolutions would then be comparable with the distances of these stars, and there might even exist, at the boundaries of the system, a certain number of very large stars, further from us than most of the stars of the Milky Way. In the galactic convolutions or near them, there would be important stars, of enormous size, centers of stellar condensations exercising a preponderating attraction on the innumerable small stars of the zone, intermixed with nebulosity. Our Sun, lying eccentrically with reference to the convolutions of the Milky Way, would nevertheless not be far from the center of the central condensation of the system, which would be at the same time the central point of the galactic convolutions.

FIG. 7.

ROTTERDAM,
March 1900.

Minor Contributions and Notes

VARIABLE STARS IN CLUSTERS. RATE OF INCREASE OF LIGHT.[1]

It appears from *Circular* No. 33, that the proportion of stars, found to be variable, in the cluster *Messier 3, N. G. C. 5272*, is greater than in any other object of the same class. This object is, however, so low at Arequipa, and the stars are so faint, that satisfactory photographs cannot be obtained of it, with the 13-inch Boyden refractor, with exposures of less than 90 minutes. The rate of increase of the light of many of these stars is extremely rapid, and in order to determine this change with the greatest precision, photographs having very short exposures are necessary. Accordingly, at my request, Professor James E. Keeler has taken a series of admirable photographs of the cluster with the 3-foot Crossley reflector of the Lick Observatory. These photographs were taken on May 20 and 21, 1900. The first plate had an exposure of 60 minutes, the others, 24 in number, exposures of 10 minutes each. Professor Bailey, from an examination of these photographs, has derived the following results:

Three variable stars have already been measured on these plates. They are Nos. 11, 96, and 119. The series of plates extended from $17^h\ 42^m\ 46^s$ to $20^h\ 24^m\ 11^s$, on the night of May 20, and from $17^h\ 2^m\ 38^s$ to $20^h\ 53^m\ 27^s$, May 21, G. M. T. These periods of time covered the entire interval from minimum to maximum, for each of the above stars, on at least one night. The same stars were also measured on 49 plates made at Arequipa during the years 1895–1899. From a study of all these measures the periods have been determined as follows: for No. 11, $12^h\ 12^m\ 25^s$; for No. 96, $12^h\ 0^m\ 15^s$; for No. 119, $12^h\ 24^m\ 31^s$. For the following discussion of the rate of increase, however, only plates made by Professor Keeler on the night of May 21, and having exposures of 10 minutes were used.

The measures of the brightness of the variables were made by Argelander's method, using a sequence of comparison stars, whose magnitudes have not yet been determined. The results are therefore given in grades. The value of one of these grades is somewhat

[1] *Harvard College Observatory Circular* No. 52.

uncertain, but is not far from one tenth of a magnitude, since in previous work by the same observer the value of one grade was found to be 0.085 of a magnitude. The observations were plotted, using vertical distances to represent magnitudes and horizontal distances, time. A smooth curve was then drawn through them. The time scale employed in the drawing was very open, in order to read with greater accuracy the ordinates of the curve corresponding to intervals of 5 minutes. The results of the measures are very accordant. For all the measures on the Lick plates of 10 minutes exposure, the average deviation from the curve is less than half a grade. The results for the three stars, for the period of increase of the light, are given below. The first column contains the time, and the second, the corresponding brightness expressed in grades. The differences, found by subtracting each value in the second column from that following it, are given in the third column, which therefore represents, in each case, the change in light during an interval of five minutes.

INCREASE OF LIGHT.

Var. No. 11			Var. No. 96			Var. No. 119		
Time	Gr.	Diff.	Time	Gr.	Diff.	Time	Gr.	Diff.
h m			h m			h m		
18 20	0.0	0.0	19 30	0.0	0.0	17 25	0.0	0.0
25	0.0	0.3	35	0.0	0.4	30	0.0	0.6
30	0.3	0.8	40	0.4	1.1	35	0.6	1.0
35	1.1	1.2	45	1.5	1.7	40	1.6	1.2
40	2.3	1.4	50	3.2	2.1	45	2.8	1.4
45	3.7	1.6	55	5.3	2.4	50	4.2	1.5
50	5.3	1.8	20 0	7.7	2.5	55	5.7	1.5
55	7.1	1.9	5	10.2	2.3	18 0	7.2	1.5
19 0	9.0	1.9	10	12.5	1.8	5	8.7	1.4
5	10.9	1.9	15	14.3	1.2	10	10.1	1.3
10	12.8	1.8	20	15.5	0.7	15	11.4	1.2
15	14.6	1.5	25	16.2	0.4	20	12.6	1.2
20	16.1	0.8	30	16.6	0.1	25	13.8	1.0
25	16.9	0.4	35	16.7	0.0	30	14.8	0.9
30	17.3	0.2	40	16.7	..	35	15.7	0.7
35	17.5	0.0	..	....	..	40	16.4	0.4
40	17.5	..	..	....	..	45	16.8	0.2
..	....	..	..	....	..	50	17.0	0.0
..	....	..	..	....	..	55	17.0	..

From this table it appears that the total increase of light, amounting to 17.5 grades, takes place in the case of Variable No. 11 within 70 minutes; in the case of No. 96, an increase of 16.7 grades occurs within 60 minutes; and No. 119, 17.0 grades within 80 minutes. The maximum increase, during any interval of 5 minutes, is, in the case of

No. 11, 1.9 grades; No. 96, 2.5 grades; No. 119, 1.5 grades. During 30 minutes No. 11 increases in light 10.9 grades, or at the rate of 21.8 grades per hour; No. 96, 12.8 grades, or at the rate of 25.6 grades per hour; and No. 119, 8.6 grades, or at the rate of 17.2 grades per hour. The greatest rapidity is in the case of No. 96, which increases, during 5 minutes, at the rate of 30 grades, or at least two and a half magnitudes per hour, and during 30 minutes at the rate of more than two magnitudes per hour. This rate of change appears to be the most rapid of any known variable. The *Algol* variable *U Cephei*, which perhaps undergoes the most rapid change of any star not found in clusters, changes at the rate of about one and a half magnitudes per hour, during the half hour of its most rapid increase and decrease. The total times of increase for the three stars, 70 minutes, 60 minutes, and 80 minutes, are 10, 8, and 11 per cent., respectively, of their entire periods. Near the beginning and end of increase, however, the rate of change seems to be relatively slow. If we allow one and a half grades for each of these periods of slow change, making three grades in all, we find that the remaining increase, amounting to more than four fifths of the whole change in light, takes place for the three stars in 42 minutes, 34 minutes, and 54 minutes, respectively, that is, in about 6, 5, and 7 per cent. of the respective full periods. In the case of No. 96, this increase is about ten times as rapid as the corresponding decrease. In general it may be stated that the length of periods and the form of light curves are similar to those of many of the variables in *Messier 5*, and in *ω Centauri* (ASTROPHYSICAL JOURNAL, **10**, 255). It will be noted that the periods of these three stars in *Messier 3* are about one half a day. Several other variables in this cluster appear to have approximately the same period.

EDWARD C. PICKERING.

June 18, 1900.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

BULLETIN NO. 15.

PHOTOGRAPHS OF STAR CLUSTERS MADE WITH THE FORTY-INCH VISUAL TELESCOPE.

THE objective of the 40-inch telescope is corrected for visual observations, the minimum focus corresponding to about λ 5800. The color curve is very steep from λ4800 toward the violet, and the difference

in focus between D and K amounts to about 130 mm.[1] It is thus eminently unsuited for photographic work with ordinary plates sensitive to blue light. The expedient of providing a third lens, of large aperture, to be placed in front of the 40-inch objective for the purpose of uniting the blue rays in a common focus, although successfully employed in the case of the Lick telescope, was not adopted for several reasons. The principal objections to such a correcting lens include its great weight and cost; the serious increase in absorption for the shorter wave-lengths; and the inconvenience arising from the change of focus, which brings the focal plane of the triple combination far up in the tube. Small correcting lenses, placed near the principal focus, have been employed with excellent effect in photographing the more refrangible regions of stellar spectra. On account of the small field of such lenses they cannot be used to photograph large groups of stars. In solar photography with the spectroheliograph, although violet light is employed, no difficulty is experienced from the steepness of the color curve, because the sensitive plate is exposed to a single line in the spectrum, and shielded from all other radiations. It remained, however, to perfect a method by which the advantages arising from the great focal length and high separating power of the 40-inch objective could be realized in direct stellar photography.

In 1892, while photographing the Moon with the 12-inch telescope at the Kenwood Observatory, Mr. G. W. Ritchey suggested that the 40-inch Yerkes telescope, then in process of construction, could probably be used to advantage for similar work. In an article on astronomical photography published about that time he explained the use of a color screen, in immediate contact with the plate, for cutting out the more refrangible rays, and pointed out that isochromatic plates, then only recently obtainable in commerce, should in large measure compensate for the loss of blue light. In 1897 some excellent photographs of the Moon were obtained by Mr. Ellerman and the writer with the 40-inch telescope, using a thin yellow screen in front of isochromatic plates.[2] These photographs are very sharp, and compare favorably with negatives taken with the Lick telescope and 33-inch correcting lens. The investigation could not be continued at that time, on account of the pressure of other work. So far as is known no attempt has hitherto been made to utilize a visual telescope in this way for

[1] See this JOURNAL, 10, 94, 1899.

[2] First Annual Report of the Director of the Yerkes Observatory, p. 9.

PLATE XVIII

PHOTOGRAPH OF THE CLUSTER *MESSIER 13*

TAKEN WITH THE 40-INCH YERKES TELESCOPE BY G. W. RITCHEY

photographing faint objects, such as the fainter stars, star clusters and nebulæ.

This work has recently been taken up by Mr. Ritchey with the 40-inch telescope, and he has already obtained excellent results. Special color screens of thin plate glass, coated with very transparent collodion of a delicate greenish-yellow tint, were prepared under his direction by the Carbutt Dry Plate Company. Short exposure photographs of stars, made on isochromatic plates in immediate contact with the absorbing screen, were so successful as to show beyond doubt the feasibility of photographing faint stars with long exposures. A special plate-holder, provided with screws for moving the plate with guiding eyepiece in two directions at right angles to each other, was designed by Mr. Ritchey, and constructed in our instrument shop under his supervision. As the apparatus was intended primarily for experimental purposes, and especially for photographing star clusters, a yellow screen only three inches square (about 14′ of arc) was employed. The guiding eyepiece (power about 1000) which is used in conjunction with a right-angle prism, stands just beyond the edge of the sensitive plate. It is supported on a slipping piece, and can be moved in two directions so as to permit a suitable guiding star to be found. In its focal plane are two fine cross-hairs intersecting at right angles, and illuminated by a small incandescent lamp controlled by a rheostat. In the exposures so far made no difficulty has been experienced in guiding with a twelfth magnitude star.

Plate XVIII is a reproduction (enlarged 22 diameters) of a photograph of the great cluster in *Hercules, Messier 13*, obtained by Mr. Ritchey on August 9, 1900, with an effective exposure of ninety minutes. The original negative shows by actual count about 3200 stars, a large proportion of which are lost in the reproduction. In spite of the fact that the Moon was nearly full, and that a part of the exposure was made through passing clouds, the plate was but little fogged after a half hour's development. The diameter of the smallest stars does not exceed one second of arc, and faint double stars of but little more than 1″ distance are clearly separated. With such excellent definition, and in view of the fact that stars as faint as the sixteenth magnitude appear on the plate, it is evident that the 40-inch telescope with this inexpensive attachment may fairly be regarded as a very efficient photographic instrument. As there is no reason to doubt that fields fifteen inches square can be photographed with a larger plate-holder, it appears

probable, from Mr. Ritchey's results, that the large telescope will henceforth be available for all classes of stellar photography. The large scale of the photographs and the small diameter of the images render the plates of great value for purposes of precise measurement.[1]

Yellow absorbing screens have been tried before with visual telescopes for lunar photography, but it does not appear that the advantages of the method have been appreciated. Mr. Ritchey's combination of a special color screen with an isochromatic plate and an efficient guiding device has yielded results which should encourage the use of other large visual telescopes for photographic investigations.

GEORGE E. HALE.

August 10, 1900.

COMPARISON OF A PRISM AND A GRATING SPECTROSCOPE.

IN considering the refraction of light the question arises as to whether it requires time for the medium to reach a steady state; *i. e.*, whether a short train of waves is refracted in the same way as a long train of the same period. As an attempt to answer this question Professor Henry A. Rowland suggested that Dr. A. W. Ewell and I should adjust a plane grating spectroscope and a prism spectroscope with a long train of prisms, so that we could examine the spectrum of the same source in each instrument; then adjust the slit so that when the source is continuous (*e. g.*, an arc lamp) the spectrum is as nearly as possible the same in both instruments; then replace the arc by a very quick spark and again compare the spectra. If the initial disturbance is refracted differently from a continuous one, then in the second case the lines as seen in the prism instrument should be broadened or rendered hazy on one or both sides as compared with the same lines in the grating spectroscope.

We used a small plane grating and a two-story Grubb spectroscope with an equivalent train of ten $4\frac{1}{2}$ cm sixty-degree prisms, whose index of refraction for the D lines was about 1.6; and we examined the *b* group of lines, where the dispersions of the two instruments were nearly the same. Owing to the faintness of the spark spectrum as given by the Grubb instrument the results are unsatisfactory; but we

[1] It will, of course, be necessary to investigate the possible effects of distortion arising from the use of the color screen.

saw not the slightest effect. The total duration of the light from each spark of the specially constructed condenser was about 10^{-7} seconds, as measured with a rotating mirror. While this is too short to give sufficient light, it is probably much too long to render the effect sought visible, even under good conditions.

The faintness of the spectrum given by the Grubb spectroscope as compared with that of the grating was so surprising that it seemed advisable to make a rough comparison of the relative efficiencies of the two instruments. By the efficiency of a spectroscope I mean the ratio of the product of the intensity of the spectrum by its width to the total amount of light striking the first prism, or grating, as the case may be. Adopting this definition, it was found that for a continuous spectrum of moderate intensity the grating spectroscope is in the red four, in the yellow five, in the green six, and in the blue eight times as efficient as the Grubb instrument.

N. Ernest Dorsey.

Johns Hopkins University,
May 1900.

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The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wavelengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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